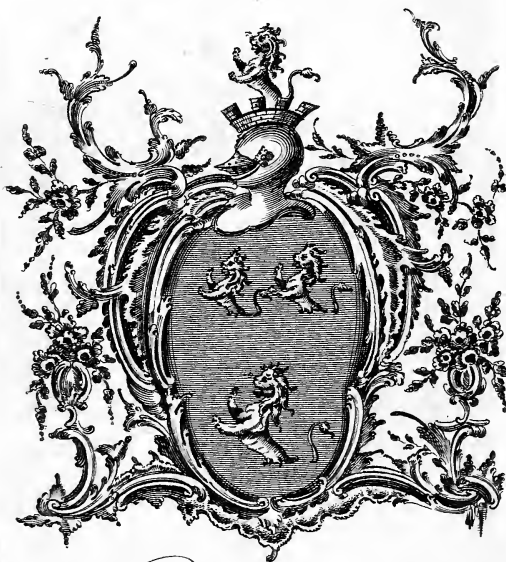




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A N
E S S A Y
O N T H E
VITAL and other INVOLUNTARY
MOTIONS of ANIMALS.

By ROBERT WHYTT, M. D. F. R. S.
Physician to his MAJESTY,
Fellow of the Royal College of PHYSICIANS,
A N D
Professor of Medicine in the Univerfity of *Edinburgh*.

Inanimum est omne quod pulſu agitur externo; quod autem eſt animal, id motu cietur interiore et ſuo. Nam hæc eſt propria natura animi atque viſ. — Quæ ſit illa viſ, et unde ſit intellegendum puto. Non eſt certè nec cordis, nec ſanguinis, nec cerebri, nec atomorum.

CICERO. Diſput. Tuſcul. lib. I.

The ſecond Edition, with Correſtions and Additions.

EDINBURGH:
Printed for JOHN BALFOUR.

M,DCC,LXIII.

ESSAYS
ON THE
VITAL AND OTHER PHYSIOLOGICAL
MOTIONS OF ANIMALS

BY ROBERT WHITT, M.D. F.R.S.
Physician to his Majesty
in 2011 with funding from

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TO the RIGHT HONOURABLE

JAMES Earl of MORTON,

Lord ABERDOUR, &c. &c. &c.

IT is not your Lordship's high station in the world, but your extensive knowledge of the works of nature, and taste for Philosophical inquiries, which have determined me to inscribe the following Essay to your Lordship, and makes me, with pleasure, embrace this opportunity of publicly declaring the great respect with which I am,

My LORD,

Your LORDSHIP'S

most obedient, and

most humble Servant,

ROBERT WHYTT.

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ABOUT twelve years since, not long after the Author of this Essay had left the schools of Medicine, he began to be dissatisfied with the common theories of respiration and the heart's motion; and as he had not met with any writer, who had given, as he thought, a just account of the vital and other involuntary motions of animals, or derived them rightly from their true SOURCE, he purposed sometime or other to write on this subject, if not for the publick, at least for his own satisfaction. In pursuance of this resolution, the following Essay was begun in the year 1744; and might have been finished long ago, had not the author's time been greatly taken up with more necessary business.— In composing it, he has been careful not to indulge his fancy, in wantonly framing hypotheses, but has rather endeavoured to proceed upon the surer foundations of experiment and observation.

tion. No doctrine in Philosophy, which was not built on these, has ever been able to stand its ground for half a century ; and the theories of NEWTON, and some few others of the more happy Philosophers, have therefore triumphed over all objections, because they were founded on nothing else but plain facts ; facts indeed, whose existence was perhaps unknown before, and whose influence is so extensive, that while they are simple and uniform in themselves, they serve as causes for explaining innumerable effects. On the other hand, in the hypothetical method of philosophising, causes are usually assigned, which not only cannot be proved to exist, but which are frequently more intricate and complex than even the effects to be explained from them. And indeed, it cannot be expected that unguided imagination should hit upon the truth, since nature has so closely concealed many of her operations, that they often elude the united efforts of genius, industry and experiment.

There

There is one favour which the author would ask, of those who may take the trouble to peruse this performance, viz. that they would delay passing judgment upon any PART of it, till they have attentively and fairly considered the WHOLE ; because it is apprehended, that the theory of every one of the motions here explained, supports and strengthens what is said of the rest, and that when all are taken together, each receives an additional weight of argument, and appears in a stronger light.

EDINBURGH,
OCTOB. 1. 1751.

ERRATA.

- Pag. 23. lin. 14. for *excited* lege *excite*.
 P. 232. l. 19. for *Deaths* lege *Death*.
 P. 276. l. penult. after *below* add ,
 P. 282. l. 16. for ! lege ?
 P. 291. l. 25. after *tickling* instead of . lege ;
 P. 302. l. 18. for *topu* lege *to put*.
 P. 333. l. 8. for *doze* lege *dose*.

The following is a list of the names of the persons who have been appointed to the various offices of the County of Los Angeles, California, for the year 1900:

[illegible]

1971.1.24.604

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OF THE
VITAL and other
INVOLUNTARY MOTIONS
OF
ANIMALS.

INTRODUCTION.

PHYIOLOGICAL writers have divided the motions of animals into voluntary, involuntary, and mix'd.

THE voluntary motions are such as proceed from an immediate exertion of the active power of the will. The involuntary and mix'd motions (which last, though subject to the power of the will, yet are not ordinarily directed by it) may be aptly enough comprehended under the general denomination of SPONTANEOUS ; since they are per-

formed by the several organs as it were of their own accord, and without any attention of the mind, or consciousness of an exertion of its active power: such are the motions of the heart, organs of respiration, stomach, intestines, &c. ; which have been, also, distinguished by the name AUTOMATIC ; though perhaps there is an impropriety in this term, as it may seem to convey the *idea* of a mere inanimate machine, producing such motions purely by virtue of its mechanical construction: a notion of the animal frame, which ill agrees with the inactivity and other known properties of matter.

ALTHOUGH we may be at a loss to explain the nature of that substance in the nerves, by whose intervention the mind seems to act upon the muscles ; and though we may be unacquainted with the intimate structure of those fibres upon which this substance operates, yet we have no room to doubt that voluntary motion is produced by the immediate energy of the mind ; manifold experience convincing us, that though there be required certain conditions in the
body

body in order to its performance, it is nevertheless owing to the will. Nor ought we to be surprised when we meet with these kind of difficulties; for they attend most of our inquiries and researches:—Thus, though the laws of motion and gravitation be fully understood and demonstrated by philosophers, yet the first cause of motion, the manner in which it is communicated to bodies, and the nature of gravity itself, have never been explained.

BUT how it comes to pass that many of our muscles are brought into contraction, not only without the concurrence of the will, but in opposition to its strongest efforts, and why most of the organs of spontaneous motion are continually agitated with alternate contractions and relaxations, of which we are no ways conscious, while the muscles of voluntary motion remain at rest, and are not contracted but in consequence of a determination of the will to that end; are questions which have occasioned no small debate among medical writers, and which as yet they are far from being agreed about.—To clear up these points, is the principal

principal design of this *Essay*; and I flatter myself that the following account of the vital and other involuntary motions of animals, will not less recommend itself to equal judges by its simplicity, than by its agreeableness to the known laws of the animal œconomy, and the easy solution it affords of all the *phenomena* of the human frame respecting its involuntary motions.

NATURE, as far as we can judge from the plan and scheme of things surrounding us, delights in simplicity and uniformity, and, by general laws applied to particular bodies, produces a vast variety of operations; nor is it at all improbable that an animal body is a system regulated much after the same manner. Following the path, therefore, which Nature has pointed out in her other and more grand operations, I have in this *Essay* endeavoured to shew, that all the spontaneous motions of animals are explicable upon the same principle, and owing to one general cause. How far some authors of great note have been unsuccessful in their inquiries into this matter, from their neglecting so obvious an analogy, and endeavouring to explain

explain the vital motions of almost every different organ, by a different theory, is left to the Reader to judge.

As the heart is one of the principal organs of the body, and its action immediately necessary to life, I shall begin with inquiring into the cause of its alternate contraction and relaxation, and whence it comes about that these motions are performed without the mind's seeming to have any concern in them, nay in opposition to the strongest efforts of the will. But it will be necessary, previously, to lay down a few *postulata*, as a ground-work upon which is to be built our theory of the involuntary motions of animals in general, and of that of the heart in particular.

S E C T. I.

Principles and facts necessary to be premised.

- I. **A** CERTAIN power or influence lodged in the brain, spinal-marrow and nerves, is either the immediate cause of the contraction

contraction of the muscles of animals, or at least necessary to it.

THE truth of this is put beyond all reasonable doubt, by the convulsive motions and palsies affecting the muscles, when the *medulla cerebri*, *medulla oblongata* and *spinalis*, are pricked, or any other ways irritated or compressed; as well as from observing that animals lose the power of moving their muscles, as soon as the nerve or nerves belonging to them are strongly compressed, cut through, or otherwise destroyed. Of this many instances might be given: But we shall content ourselves with mentioning one, which is too strong and unexceptionable to admit of any evasion. When the *recurrent* nerve on one side of the *larynx* is cut, the voice becomes remarkably weaker; when both are cut, it is entirely and irrecoverably lost*, *i. e.* the animal loses all power of moving the muscles which serve to increase or diminish the aperture of the *glottis*; for I presume it will be needless now-a-days to go about to shew, that the

tying

* Edinburgh Medical Essays, vol. 2. art. 8.

tying of those nerves can only affect the voice, by rendering these muscles paralytic*.

IF

* In the *Comment. acad. Bonon. vol. 2. part 2.* there are related by *Molinelli*, the histories of two patients, who, though they had, in the operation for the aneurism in the arm, the nerve tied along with the artery, yet recovered, after about three months, the entire use of that member; whence some have not scrupled to conclude, that the nerves are not necessary to motion or sensation. But in this they have rather been too hasty; for *Galen* informs us, that as often as a nerve has been quite cut through, the muscles to which it belonged were deprived both of sense and motion†: and many later examples might be produced, where the same consequence attended the destroying of a nerve. I shall only mention one, which is consistent with my own knowledge. *J. F.* who had the nerve tied along with the artery in the operation for the aneurism eighteen years ago, continues, to this day, to have a numbness and feebleness of the muscles of the thumb and forefinger, which are also a good deal shrivel'd. — But further, it appears, even from the histories now mentioned, that the immediate consequence of a ligature made upon the nerves was a total loss of motion and sensation in the parts below; and this happened notwithstanding that the blood continued, by two pretty large arterial branches, to be distributed to them: which is such a direct proof of the necessity of the nerves to motion and sense, as is not to be overturned by the parts recovering afterwards their power of motion, since this might happen without any inconsistency to the former conclusion, and in a way
unknown

† De motu musculorum, lib. 1. cap. 1.

If the brain were not in a manner the fountain of sensation and motion, and more peculiarly the seat of the mind than the other *viscera* or members of the body; why should a slight inflammation of its membranes cause madness, or a small compression of it produce a palsy or apoplexy, while a like inflammation of the stomach or liver, or a compression or obstruction of these bowels, have no such effects? If the nerves

unknown to us. — In the history found by *Morgagni* among *Valsalva's* papers, and related in the same volume of the *Comment. Bonon.* we are told, the patient did not recover the full use of his arm till eight or nine months after the operation for the aneurism was performed. When *Molinelli* dissected this arm, thirty years after, he found the nerve not wanting in the place where the ligature had been made, as were the artery and vein, but of a much greater thickness than usual, and not unlike a *ganglion*. From this observation, I think, we have reason to believe, that, in *Molinelli's* two patients above mentioned, the nerve was not destroyed by the ligature, but perhaps acquired a greater thickness in that part, and so became, after some months, fit to perform its functions.

Upon the whole, the histories of the operation for the aneurism related in the Bononian transactions, though they may perhaps confound a superficial inquirer, will never incline an accurate and impartial one to reject the doctrine of the nerves being necessary to motion and sensation.

nerves were not immediately concerned in muscular motion, why, upon tying or destroying them, does the member to which they are distributed, lose all power of motion as well as sensation? — Because animals have lived with a brain so diseased, that it is difficult to conceive how it could perform its functions, or because monsters which have been born without a head, lived some short time, and had the power of motion; to conclude, I say, from hence, that the brain and nerves in perfect animals are not immediately necessary to motion and sensation, is altogether as absurd, as it would be to assert, that the heart was not designed to propel the blood through the body, because there are several animals of the lowest class, which have no such organ*, and monstrous fœtuses have sometimes wanted it†; or because we are told of a rat every way healthful, which being dissected was found to have no heart‡.

—No reasoning drawn from a few mon-

B

strous

* *Harvey* de motu sang. cap. 17.

† *Memoires acad. sciences* 1725, edit. 8vo, p. 16.

‡ *Van Swieten* comment. in Boerhaav. aphorism. vol. 1. p. 256.

strous cases, can be sufficient to overthrow a doctrine founded upon the plainest *phenomena* observed in perfect animals, and confirmed by almost numberless experiments made upon them. The necessity therefore of the influence of the brain and nerves towards producing muscular motion, is not to be disproved by a few rare instances of ossified, petrified, or otherwise morbid brains found in animals, which seemed tolerably healthy, and had the motion of all their muscles; since it is not more unreasonable to suppose, that the nerves may derive nourishment from a porous spongy ossified brain, than that a tree should spring out of a stone-wall; dry stone and lime being not less different from moist earth, than such an ossified brain from one in its natural state; nay the latter seems more capable of affording moisture to the nerves, than the former to roots of the tree*.——When
the

* The brain mentioned by *Duverney*, in *Memoires acad. des sciences* 1703, edit. 8vo, p. 318. &c. was not wholly petrified; its inferior part from which the nerves take their rise, still retained its medullary form. And the same has probably been the case of other petrified or ossified brains, tho' perhaps not so accurately observed.

the brain is wanting, Nature may have other ways of supplying the nerves, and of keeping them in such order, as that they may be able in some sort to perform their functions. And since the spinal-marrow not only depends, for its powers, on the brain from which it proceeds, but also on a particular secretion performed by its own blood-vessels, we may reasonably conclude, that the nerves proceeding from the brain and spinal-marrow are, partly, nourished and kept in a proper state for action, by the fluids conveyed to them, by the small arteries which are distributed on their surrounding membranes. This opinion is strongly supported by those instances, which are to be found in the writings of Physicians, of children born without any brain or spinal-marrow; for in those children, the nerves must have derived all their nourishment from the blood-vessels bestowed on their coats.

THE immediate cause of muscular contraction, which, from what has been said, appears evidently to be lodged in the brain and nerves, I chuse to distinguish by the
terms

terms of the *power* or *influence* of the nerves; and if, in compliance with custom, I shall at any time give it the name of *animal* or *vital spirits*, I desire it may be understood to be without any view of ascertaining its particular nature or manner of acting; it being sufficient for my purpose, that the existence of such a power is granted in general, though its peculiar nature and properties be unknown.

2. WHILE the nervous power is immediately necessary to muscular motion, the arterial blood seems to act only in a secondary or more remote manner.

MUSCLES are immediately rendered paralytic upon tying or destroying the nerves distributed to them*. But when the arteries bestowed upon any muscles are tied, the action of these muscles is only gradually weakened, and not totally abolished till after a considerable time. The ingenious Dr. *Langrish* tied up and cut asunder both the carotid and both the crural arteries of the same dog, without destroying the motion

* *Kaau* impet. faciens, N^o. 288.

tion of one muscle* ; and Dr. *Swencke* assures us, that, after having tied the crural artery of a dog, close by the groin, the animal continued to move his leg and foot for a whole day ; the same experiment he repeated in another animal, and did not find that the muscles of the leg became paralytic till this member was almost quite dead †. 'Tis true indeed, that, by a ligature made on the *aorta*, immediately above its division into the iliacs, the hinder limbs of a dog gradually lost their motion, and became quite paralytic after two minutes ‡ : from which it may be thought, that, in the experiments of *Langrish* and *Swencke*, the motion of the muscles continued longer, because they had still some blood transmitted to them by lateral communicating branches, from arteries which were not tied. But, on the other hand, it seems more probable, that a ligature on the *aorta* renders the muscles of the legs paralytic, by depriving the inferior part of the spinal-marrow,

* Cronean lectures on muscular motion, § 93.

† Hematolog. p. 8. See also Brunner. de pancreat. p. 188.

‡ *Kaau* impet. faciens, N^o. 291.

marrow, and the nerves proceeding from it, of that blood which contributes to nourish and keep them in a sound state [1.].

FROM what has been said, we may fairly conclude, that the arterial blood sent to the muscles is only necessary to their motion, in so far as it supplies the vessels and fibres of the muscles with fluids proper for their nourishment, gives them a suitable degree of warmth, and thus preserves them in such a state, as may render them most fit to be acted upon by the nervous power. While therefore the nourishment and growth of the muscles are owing to the motion of the arterial blood through their vessels, their powers of motion and sensation proceed from the nerves alone.

3. THE muscles of living animals are constantly endeavouring to shorten or contract themselves. Hence such as have antagonists are always in a state of tension ; and the solitary muscles, such as the sphincters, and those whose antagonists are weakened or destroyed, are always contracted,

tracted, except when this natural contraction is overcome by some superior power.

4. THE natural contraction of the muscles [3.] is owing, partly, to all their vessels being distended with fluids, which separate and stretch their smallest fibres.

As a proof of this, the muscles of animals that are in full health, and abound with proper fluids, retract themselves much more remarkably towards each extremity when cut across, than the muscles of such animals as are in a languishing state, and exhausted of their fluids; besides, that soon after death, the muscles become flaccid, and, when cut transversely, retract themselves but little.

BUT, farther, the natural contraction of the muscles is, in a great measure, to be ascribed to the influence of the nerves, which is perpetually operating upon them, though in a very gentle manner: and that to this is chiefly owing the constant contraction of the sphincters, and the tension of such muscles as are balanced by antagonists, the palsy affecting the sphincters as soon

soon as their nerves are compressed or destroyed, and the constant contraction of such muscles whose antagonists are deprived of the nervous power, evidently demonstrate.

5. THE natural contraction of the muscles [3. and 4.] arising from the constant and equable action of the nervous power on their fibres, and of the distending fluids on their vessels, is very gentle, and without any such remarkable hardness or swelling of their bellies, as happens in muscles which are contracted by an effort of the will. And although the sphincters and those muscles, whose antagonists are paralytic or hindered from acting, do always remain in a state of contraction; yet at any time, by an effort of the will, they can be much more strongly contracted. 'Tis somewhat strange that Dr. *Stuart* should have been so far mistaken, as to assert, that the mind has no manner of power over such muscles as are destitute of antagonists; not only that it cannot unbend them, which is allowed by all, but also that it cannot make them

them contract more strongly* ; for every one must be satisfied, that though the *sphincter ani* is naturally in a constant state of contraction, yet he can at pleasure make it contract more strongly ; and though the *biceps flexor cubiti* contracts and swells upon the arm's being bent by an external force, even in spite of any effort of the will to the contrary, yet any one, if he pleases, can make it swell more, grow much harder, and contract itself with vastly greater force.

FROM what has been just now advanced, it follows, that it is not necessary, in order to the mind's acting upon the muscles, that they should be stretched or extended beyond that length to which they would naturally reduce themselves, if not prevented by the action of their antagonists.

6. As often as the influence of the nerves operates more powerfully than usual on the muscles, they are excited into stronger contractions which are not natural, and therefore may be called violent. This extra-

C ordinary

* *Dissertatio de motu musculari*, p. 22, 23. and 77.

ordinary action of the nervous influence, may be owing either to the power of the will, or to a *stimulus*.

7. VOLUNTARY contraction is owing to the stronger action of the nervous influence upon any muscle, excited by the power of the will.

8. A *stimulus*, or any irritating substance applied to the bare muscles of living animals, immediately produces a contraction in them.

THIS appears from numberless experiments and observations ; and is equally true with respect to the muscles of voluntary and involuntary motion.—The muscles of a living frog, when laid bare and pricked with a needle, are strongly convulsed. — A solution of white vitriol no sooner touches the internal surface of the stomach, than this organ is brought into convulsive contractions. — Smoke of tobacco or acrid clysters injected by the *anus*, bring convulsive motions on the great guts.—Pricking the intestines or heart of a living animal,

or

or applying any acrid fluid to them, remarkably increases their contraction*. — Many other instances might be given of the effects of *stimuli* on the muscles of animals; but these may suffice, as we shall have occasion to treat of this matter more fully afterwards.

WHATEVER stretches the fibres of any muscle, so as to extend them beyond their usual length, excites them into contraction almost in the same manner, as if they had been irritated by any sharp instrument, or acrid liquor. Thus the motion of the heart in pigeons newly dead, is as remarkably renewed or increased by drawing asunder the sides of the divided *thorax*, and consequently stretching the great vessels to which the heart is attached, as by pricking its fibres with a pin †. In luxations, muscles,

by

* *Harvey*, speaking of the *punctum saliens*, or heart of the chick in the shell, says, “ Vidi sæpissime ab acus, styli, aut digiti contactu, imò vero a calore aut frigore vehementiore admoto, aut cujuslibet rei molestantis occursum punctum hoc, pulsuum varias permutationes, istiusque validiores ac frequentiores edidisse.” De generatione animal. exercitat. 17.

† Vid. *infra*, Sect. xiv. N^o 16. and 17.

by being over-stretched, are often convulsed; and the *vesica urinaria* and *intestinum rectum*, are not only excited into convulsive contractions by the acrimony of the urine and *fæces*, but also by their bulk and weight stretching the fibres of these hollow muscles*.

BECAUSE the heart and other muscles of animals, often, continue to move, for some time, after they are separated from their bodies, and consequently after all communication between them and the brain is cut off, some have thought the contraction of irritated muscles to be owing, not so much to the nervous influence, as to some latent property in their fibres. But as I have, elsewhere, sufficiently refuted this opinion†, I shall only observe, in this place, that unless the motions of irritated muscles depended upon the brain and nerves, it would be difficult to conceive why an irritation of the *medulla oblongata* or nerves, should occasion more violent convulsions of the muscles in animals
newly

* Vid. *infra*, Sect. v.

† Physiological Essays, edit. 2. appendix, p. 245 — 252.

newly killed, than an irritation of those muscles themselves.

9. IN proportion as the *stimulus* is more or less gentle, so (*cæteris paribus*) is the contraction of the muscle to which it is applied.

THE truth of this proposition, like the former, is not only proved by experience, but may be deduced from reason alone; for if the irritation is to be considered as the cause, and the subsequent contraction of the muscle as the effect; then, in proportion as the cause is increased or diminished, so must be its effect.—The motions occasioned by stretching the fibres of any muscle will be greater or less, as the muscle is more or less stretched; unless it be so far extended, as quite to lose its tone, and become paralytic.—It deserves however to be observed, that the effects of different *stimuli* depend very much upon the peculiar constitution of the nerves and fibres of the muscles to which they are applied: And hence it is, that what proves a strong *stimulus* to the nerves of one part, will more
weakly

weakly affect those of another, and *vice versa*. Thus warm water or oil, which, when drunk in a large quantity, provoke vomiting, lessen the increased alternate motion of the small vessels of a part which has been inflamed by the application of *cantharides* or any other acrid substance.—Cold water, which is very agreeable to the nerves of the stomach, excites violent coughing as often as it gets into the windpipe.—Light, which by irritating the *retina* occasions the contraction of the pupil, does not act, sensibly, as a *stimulus* on any other part of the body.—Although an injection prepared with corrosive mercury occasions considerable pain, when it is introduced into the *urethra*, yet neither it, nor the urine excites any convulsive contractions of the *musculi acceleratores urinæ*, as the *sēmen* does, altho' it is of a soft, unctuous nature, and possessed of very little acrimony. And this leads me to observe, that the motions excited in our muscles, are often not so much the consequence of pain as of a different kind of sensation: thus, when the sides, or the soles of the feet are tickled, convulsive motions

are

are excited in the muscles of the trunk of the body and legs, which, however, do not happen, when those parts are pricked with a pin or inflamed by the application of a blister or sinapism. Further, the same organs in different people are sometimes very differently affected by the same *stimuli*; thus honey excites vomiting and purging in some people; and in others, certain *effluvia* will occasion an asthmatic fit, or hysteric faintings with convulsions. I shall only add, that very hot or corrosive substances, often excite less motion in the muscles, than milder *stimuli*, because they either, at once, destroy or greatly impair the moving power of the parts to which they are applied; and hence it is, that a frog's heart ceases, almost immediately to move, when it is immersed in boiling water or oil of vitriol.

10. AN irritated muscle does not remain in a contracted state, although the stimulating cause continues to act upon it; but is alternately contracted and relaxed.

THUS

THUS the *stimulus* of an emetic received into the stomach, does not occasion a continued contraction of its muscular coat ; and an irritation of the lower extremity of the gullet, is followed by alternate convulsions of the diaphragm. The heart of a frog or eel taken out of the body, continues its alternate motions while a needle is fixed in it. When the heart or other muscular parts of dying animals cease to move, heat will renew their contraction, which is regularly alternate, although the *stimulus* be unvaried : After the auricle of a pigeon's heart had ceased to move, I made it renew its alternate contractions, by filling the *thorax* with warm water* ; and after the vibrations of a frog's heart had begun to languish, they recovered their former vigour and quickness, by exposing it to the heat of a fire.

WHEN muscles have been long in action, or too highly strained, the member to which they belong is observed to be affected with a *tremor*, which often lasts for a considerable time ; *i. e.* these muscles are agitated with
small

* Sect. xiv. No 15. of this Essay.

small alternate contractions and relaxations, notwithstanding the stimulating cause continues present with them.

It might perhaps be imagined *a priori*, that a muscle ought to remain contracted as long as the *stimulus* or cause of its contraction continues to act upon it: but the fact we see is otherwise; and the reason of it shall be explained afterwards*. But it must be here observed, that although there are scarce any of the muscles of animals whose fibres are not affected with alternate contractions and relaxations, when they are irritated with the point of a pin or other substance capable of stimulating them, yet, in morbid cases, our muscles or muscular organs are frequently affected with a continued contraction or fixed spasm; which symptom, however, is owing either to an irritation of the brain or nerves, or of the muscles themselves: nay, even in a sound state, there are a few instances of muscles which are not alternately relaxed, but remain uniformly contracted as long as the stimulating cause continues to act

D

with

* See below Sect. x. near the end.

with the same degree of force, such as the orbicular muscle of the *uvula*, the bladder of urine, and some others*.

II. IRRITATED muscles are not only agitated with alternate motions while the stimulating cause continues to act upon them, but also for some time after it is removed; although these motions become gradually weaker, and are repeated more slowly. If the irritation be great, these alternate motions last longer, and follow one another more quickly; if weaker, they are repeated after longer intervals, and sooner cease; if extremely gentle, and the muscle not very sensible, perhaps only a single contraction or two will ensue [9.].

SOME of the fibres of the *platysma myoides* which were dissected off with a tumor, have been observed to palpitate like the heart of a dying animal for a considerable time; and the same motions have been often observed in the muscles of brute animals, when

* See below Sect. x. near the end.

when their fibres were irritated after their separation from the body *.

THE heart of an animal newly killed, is excited into motion by blowing upon it, or touching it with the point of a pin; and this motion often lasts a great while, altho' the *stimulus* is not renewed. After a pigeon's heart had ceased to move, its vibrations were not only renewed by drawing asunder the sides of the divided *thorax*, but they continued for a considerable time †.

12. THE motions of muscles from a *stimulus* are altogether involuntary.

EVERY one must be sensible of the truth of this assertion, who has ever felt any of those small convulsions or pulsatory contractions, which frequently happen in different parts of the body, and which seem to be owing to some irritation of the fibres or membranes of the muscle contracted, either from acrid particles in the fluids irritating their sensible nerves, or from too great

* Vid. Sect. xiv. N^o 3.

† Sect. xiv. N^o 16. and 17.

great a distension of their tender vessels by the stagnation of the circulating fluids. The muscles called *acceleratores urinae*, though at other times entirely under the power of the will, yet, while the *semen* continues to be poured into the beginning of the *urethra*, they are agitated with strong convulsive contractions, which we can neither increase nor prevent.—When the tendinous fibres of the *obliquus inferior* of the eye, or of any other of its muscles, are gently stimulated with the point of a file, the alternate contractions which ensue, are altogether involuntary, and can neither be accelerated, retarded, augmented, nor diminished by the power of the will. The same thing is true of the motions of the stomach and diaphragm, excited by emetics. From which it follows, that,

13. THE power of *stimuli* in exciting the muscles of living animals into contraction, is greater than any effort of the will.

THE truth of this is still further confirmed, by the following observation. A man aged 25, who, from a palsy of twelve years continuance,

continuance, had lost all power of motion in his left arm, after trying other remedies in vain, at last had recourse to electricity; by every shock of which the muscles of this arm were made to contract; and the member itself, which was very much withered, after having been electrified for some weeks, became sensibly plumper.—If then, the voluntary muscles can, even in a palsied state, be excited into contraction by the action of a *stimulus* on their fibres, it follows, that when this is applied to them in a sound and more sensible state, any effort of the will to prevent their contraction, must be vain and impotent.—Hence the muscles of voluntary as well as of involuntary motion cease to be under the power of the will, while their nerves or sensible fibres are irritated by *stimuli*.

It may be observed here, that although we cannot, by an effort of the will, prevent the motion of any muscle whose fibres or nerves themselves are irritated, yet we can, in many cases, restrain the action of certain muscles, whose motions are excited by an irritation of a distant part, with which they have

have a particular sympathy; thus, we can prevent the motions of the muscles employed in coughing and in voiding the urine and *feces*, when the *trachea*, bladder and *rectum*, are only slightly stimulated; unless these parts have been rendered much more sensible than usual, by being inflamed, or deprived of their *mucus*.

14. THERE are three kinds of contraction observable in the muscles of animals, all of them different from each other, *viz.* natural [4. and 5.], voluntary [7.], and involuntary, from *stimuli* [8. 9. 10. 11. 12. 13.]. The first is very gentle, equable and continued, and is owing to the causes mentioned N^o 4. The second proceeds immediately from the power of the will, is always stronger than the former, and may be continued for a longer or shorter time, or performed with more or less force, as one pleases. The third is strong, but suddenly followed by a relaxation, seems to be a necessary consequence of the action of the *stimulus* upon the muscle, and cannot be affected,

affected, either as to its force or continuance, by the power of the will.

THAT continued contraction or fixed spasm, with which our muscles are sometimes affected [10.] being almost always a morbid symptom, and not the natural or usual effect of an irritation of their fibres, its particular consideration is of less use in treating of the vital and other involuntary motions of animals in a *sound* state.

15. THE natural contraction above explained [14.] is what we observe in the sphincters, and in muscles whose antagonists are paralytic or destroyed.

16. WHILE the sphincters of the *anus* and bladder, and those muscles whose antagonists are destroyed, remain always in a state of contraction, and while such muscles as have antagonists, are kept in *æquilibrio*, or without any motion, except when the will interposes; the heart, which has no proper antagonist, is alternately contracted and dilated, without our being able, by any effort of the will, directly to hinder or promote its motions.

17. THE contraction of the heart is, therefore, not only involuntary, but of a different kind from that of the sphincters and muscles deprived of antagonists; and seems, as to its *phenomena*, to agree with the contraction of muscles from a *stimulus*. [14.].

18. THE mind may, by disuse, not only lose its power of moving even the voluntary muscles, except in a particular way, but also of exciting them into contraction at all. Of the former we have an example in the uniform motions of the eyes; and of the latter in the muscles of the external ear, and of such members as have remained long without motion.

S E C T.

S E C T. II.

An examination of the opinions of some of the most considerable authors concerning the motion of the heart.

IT seems to have been the prevailing opinion among many of the ancient Physicians, that the motion of the heart was owing to a vital principle particularly residing in it. *Galen* thought motion as natural to the heart, as rest to the other muscles.—*Des Cartes*, much less versed in Physiology than in Mathematics, attributed the motions of this organ, wholly, to the ebullition of the blood dropping into its ventricles; and contended, that this fluid was not pushed into the arteries by the muscular contraction of the heart, but that it forced its way into them by its own explosive power.—After *Harvey's* doctrine of the circulation was fully established, the heart was allowed to be a muscle, and its *systole* to be analogous to the contraction of

other muscles ; the vital spirits of the nerves were supposed to flow alternately into its fibres, either on account of valves, which by turns admitted and denied them a passage ; or because it was thought that the spirits could only be discharged by drops, and not in an equable stream, from the extremities of such subtile tubes as the nerves were conceived to be *.

VARIOUS other *hypotheses* were framed to explain the alternate motion of the heart ; a problem not less difficult than curious ! These I shall pass over in silence, leaving them to fall by their own absurdity, or the arguments of others ; and content myself with mentioning the defects of some of the latter systems, which, from their plausibility, or the high character of their authors, are intitled to the greatest regard.

THE theory of the heart's motion, which has of late years met with the most favourable reception, is that of the celebrated *Boerhaave*, who deduces the alternate *systole* and *diastole* of that muscle, chiefly from the
peculiar

* *Borell. de mot. animal. lib. 11. cap. 6. prop. 79.*

peculiar circumstances of the cardiac nerves; for as the greatest part of these nerves passes between the auricles and large arteries of the heart, he concluded that they must be compressed at the end of every *systole*, when these cavities and vessels are greatly distended with blood; whence the motion of the spirits being intercepted, the heart must be rendered paralytic; but that whenever, upon the subsequent contraction of the auricles and arteries, this compression ceases, and the nerves transmit their fluid as formerly, the heart must contract anew *.

THIS *hypothesis*, however ingenious, will appear altogether insufficient, if we impartially attend to the following considerations.

I. ALL the cardiac nerves don't pass between the auricles and arteries. Not to mention many smaller ones, there are two very considerable branches distributed to the muscular substance of the heart, which neither pass between the two auricles, nor the two arteries, and therefore cannot be liable

* Institut. med. No 409.

liable to any alternate compression from them.

2. I believe it will be difficult to persuade unbiassed inquirers, that the nerves (supposing they all had their course between the auricles and arteries) could suffer any such compression as is here required ; considering the softness of the parts, and the fat upon the external coat of the arteries and auricles, which may well be imagined to defend them in a great measure from it : besides it is strange that we do not observe other muscles of the body become alternately or constantly paralytic, whose nerves run contiguous to any considerable artery, or are compressed by any preternatural tumor. *Qui fit, obsecro, says the accurate Morgagni, ut nervi intercostalis munera ab assidua arteriæ carotidis pulsatione non turbentur, præsertim cum is nervus non possit cedere, sed communis ipsi, et arteriæ ossei foraminis parietibus allidatur ? Qui fieri posset, ut in Veneta muliere, quam cum amicis dissecuimus, cum arteriæ subclaviæ sinistræ superiores posticque parietes in aneurisma expansi, duos tresve nervos ex iis*
qui

qui ab inferioribus cervicis vertebrae ad brachium descendunt, nulla prorsus interposita re contingerent; qui fieri, inquam, posset, ut nulla tamen debilitas, nullus torpor in eo brachio fuerit animadversus.?*

WHY are not all the *viscera* in the abdomen, to which the intercostal nerves are distributed, agitated with alternate contractions answering to those of the diaphragm, since these nerves, by passing through the fleshy part of this muscle, must be liable to compression every time inspiration is performed? And why do not many of the voluntary muscles, when strongly contracted, occasion palsies or stupors of the parts below them, by pressing upon the nerves to which they are contiguous?

3. It is to be remarked, that a slight compression of a nerve is not sufficient to render the muscle to which it belongs paralytic: thus the ulnar nerve must be pretty strongly compressed against a hard bone, before the ring and little fingers are deprived of their power of motion; nor does this
happen

* *Morgagni adversar. anat. vi. animad. 24.*

happen without being attended with a disagreeable sensation in these parts.

4. As the compression of the ulnar nerve does not immediately bring a palsy on the muscles of the fingers now mentioned, but after it has been continued for some considerable time ; so when this pressure is removed, the motion of these muscles does not return immediately and all at once, but by degrees, and not till after some time : wherefore, allowing the cardiac nerves were alternately compressed by the auricles and arteries, yet the heart ought not to be rendered instantly paralytic by such compression, nor should it recover its motion as soon as this compression is removed. But further,

5. GRANTING the cardiac nerves suffered as great compression in their passage, between the auricles and arteries, to the heart, as the advocates for this opinion could desire ; what will follow ? an effect surely altogether different from that which is here contended for ; since the immediate consequence of such compression must be the

the squeezing forward towards the heart, the spirits *supposed* to be contained in that portion of the nerves which is below where the compression is made ; for if the nerves are supposed to be hollow tubes which convey a fluid to the heart in order to its contraction, the first and most immediate effect of their being compressed by the dilatation of the auricles and arteries, must be a quicker propulsion and more copious derivation of the spirits into its fibres ; *i. e.* the heart ought to be most strongly contracted, at the time its *diastole* is observed to begin. And in fact we find, that a ligature made on the *par vagum* is so far from rendering the heart *immediately* paralytic, and preventing its contraction, that it causes strong convulsive motions or palpitations of this muscle ; although these, indeed, are rather to be ascribed to the irritation which those nerves suffer than to any propulsion of the spirits, supposed to be contained in them, towards the heart *.

6. THIS

* See below Sect. xiv. No 26. 2.

6. THIS supposed alternate compression of the cardiac nerves by no means accounts for the motion of the auricles, whose *systole* happens when *their* nerves ought to be compressed, and consequently when the derivation of the spirits into them should be intercepted. If it be said, that the auricles are ready to contract when the *systole* of the ventricles begins, but that, being weaker muscles, they must wait till this is over*? I answer, that, if this were true, the auricles should become pale and tense while the ventricles are contracted, since, when the influence of the nerves acts more strongly on any muscle, it becomes equally hard, whether it be allowed to contract, and its extremities to approach each other, or not. But further, as an influx of spirits into the fibres of any muscle, must be immediately followed by an endeavour in them to contract, so if this be prevented, as soon as the spirits are again intercepted, their influence to produce any contraction will cease. This is evidently the case with such muscles as are under the power of the will, where
any

* *Bellin.* de motu cord. prop. 2. *Keil's anatomy* cap. 3. sect. iv.

any sudden but not continued effort, if it is not allowed that instant to take effect, immediately vanishes; nor is it to be doubted, that the same thing must happen to the auricles of the heart. But, be this as it will, it is evident, that the alternate motions of the auricles cannot be owing to any compression of their nerves; since it is acknowledged, by the best Anatomists, that the course of these nerves is such, as cannot subject them to any alternate pressure; which is also true of all the cardiac nerves in those animals whose hearts have only one ventricle.

7. IN dying animals, the right ventricle continues to contract after the left one has ceased, and the right auricle performs its motions for some time after its ventricle*. But these alternate motions of the right ventricle and auricle cannot, possibly arise from any compression of their nerves; since, in the first case, neither the *aorta* nor left auricle are dilated with blood at the end of the *systole* of the right ventricle; and

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* *Harvey de mot. cord. et sang. cap. 4.*

in the latter, the pulmonary artery also remains empty. In frogs and fishes, whose heart has but one ventricle and one artery going out from it, the alternate motions of this organ are as regular as in men and quadrupeds: and it is well known, that the hearts of many animals, after being separated from their bodies, continue for some time to be alternately contracted and relaxed with great regularity, when there can be no alternate compression to intercept the nervous influence at the end of every *systole*.

8. LASTLY, It may well be looked upon as a defect of this theory of the heart's motion, that it does not any ways assist us in explaining the spontaneous action of other organs in the body, whose nerves cannot, with any colour of reason, be supposed liable to an alternate compression.

SOME have imagined, that, as the intercostal nerves pass through the same holes of the *cranium* with the carotid arteries, they must, therefore, suffer such compression from the *diastole* of these arteries, as shall render the heart paralytic at the end of every

every *systole*. In answer to which, it may be sufficient to ask, why the other muscles and *viscera* which receive nerves from the intercostals, do not exactly correspond with the heart in their motions; or why the auricles and ventricles of the heart are not contracted and relaxed at the same time?

THE learned *De Gorter*, fully aware that the supposed alternate compression of the cardiac nerves afforded no satisfactory account of the motions of the heart, supposes that vital or involuntary motion is owing to one and the same cause, both in the heart and other organs of the body: this cause he imagines to be such a structure of the involuntary muscles, that, when their fibres are dilated by the spirits, the small nerves which pass between them are compressed; so that no sooner are the fibres inflated, than the spirits are intercepted, and consequently the muscle begins to be relaxed; but this relaxation of the muscular fibres, freeing the nerves from compression, the spirits are transmitted as formerly, and the muscle is contracted anew. And in this manner he fancies that, as long as life remains,

remains, the muscles of involuntary motion must be alternately contracted and relaxed *. But,

1. NOT to mention, that this structure of the vital organs is entirely hypothetical, and unsupported by any experiment, or microscopical observation ; it may be asked, why all the vital organs are not contracted, and relaxed at the same instant ; or at least why the motions of some are renewed after shorter, and of others after longer intervals ?

2. If such were the structure of the muscles of spontaneous motion, that their contraction must be immediately followed by their relaxation, how comes it, that, by an effort of the will, we can keep the diaphragm in its strongest state of contraction, as long as we please ? and why does not the relaxation of this muscle necessarily follow its contraction, if its alternate motions depend on a general structure, common to it with the heart and intestines ;

3. IN

* *Cortier de motu vitali*, sect. 39.

3. IN cases where the lungs are obstructed and respiration is rendered difficult, we find, that, even in time of sleep, other muscles besides the common inspiratory ones are brought into alternate contractions, in order to raise the ribs, and enlarge the cavity of the *thorax*; whence it appears, that muscles of the voluntary kind may, on certain occasions, be employed in the performance of the vital motions, altho' there be nothing in the structure of these muscles peculiarly fitting them for such alternate motions.

4. FURTHER, the pupil (whose motions are as involuntary, and as little perceived by us as those of the heart) is not immediately relaxed, after having been contracted by the admission of light into the eye, but it remains in the same degree of contraction, as long as the same quantity of light is transmitted to the *retina*; which could not happen, if any such structure really obtained in the muscles of the *uvea*, as *De Gorter* supposes in the muscles of involuntary motion. We reject therefore his theo-

ry, not only as a mere *hypothesis* without any foundation, but as wholly insufficient to explain the various *phenomena* of spontaneous motion.

SOME ingenious Physiologists have imagined the contraction of the heart to be owing to the elastic power of its fibres, which, after they have been stretched by the returning venous blood dilating the auricles and ventricles, resile, like a bent bow, with a considerable force. But the force with which a spring recoils, is ever proportional to the power which bent it; wherefore, since the sides of the heart contract with a much greater power than that with which they were forced asunder, the *systole* of this muscle cannot arise merely from the elasticity of its fibres, but must be owing to some additional *impetus*, at that time, communicated to them.

THUS much being premised, in order to shew the weakness and insufficiency of some of the most plausible theories, that have hitherto appeared concerning the heart's motion; we shall endeavour, in the following Section, to give such an account of its *systole*,

systole, as it is hoped will appear no less supported by reason and analogy, than founded in experiment and observation, as well as strongly confirmed from its fully answering all the *phenomena*.

S E C T. III.

Of the systole of the heart.

BEFORE we inquire into the causes of the alternate motions of the heart, it will be proper briefly to mention and describe three different states of that muscle, *viz.* its contraction, relaxation, and dilatation; of which the first and last may be said to be violent, and the second only natural to the heart. During its *systole*, the heart is contracted in all its dimensions*,
and

* It has been warmly disputed, whether the heart becomes shorter or longer in the time of its *systole*. But, after carefully inspecting the hearts of frogs and several other animals, both in the body, and when separated from it, I cannot help (notwithstanding the authority of *Winslow* on the other side) agreeing with Dr. *Hunauld* and others, who affirm, that
the

and its substance becomes remarkably hard : This state, which scarcely lasts one third of the time intervening between each contraction, is followed by a general relaxation of the heart, by which this muscle becomes soft and flabby, and is rendered somewhat longer. *Bartholine* calls this the *perisystole* of the heart *. It continues a much shorter time than the *systole*, the ventricles being instantly, after their relaxation, filled with the returning venous blood, and distended much beyond their natural capacity, or that which they are observed to have in animals newly dead ; when the fibres of the heart are neither contracted nor dilated by any adventitious force, but left entirely to themselves. The *diastole* of the heart being thus fully completed, its *systole* immediately ensues.

SUPPOSING the heart now in its full *diastole* ; let us inquire what change has happened to it since the end of the preceeding *systole*,

the heart is diminished in length, as well as in breadth, when it begins to contract. Vid. *histoire acad. des sciences* 1731, edit. 8vo. p. 32. &c.

* *Anatom.* p. 37. 377, 378.

systole, which may be supposed capable of bringing it into a new contraction.—We have already shewn, that the nerves of the heart are not, at this time, freed from any compression which a little before could have rendered it paralytic. And if one should suppose some general structure in the brain, which determines the vital spirits through its nerves alternately, and as it were in succeeding waves, yet this would not account for the motions of the heart ; since the alternate contractions of this muscle continue for some time after all communication between it and the brain has been cut off. Further, as the contractions of some of the organs of vital motion are performed after shorter, of others after longer intervals, we must necessarily suppose, at the origin of the nerves belonging to each organ, a different cause alternately determining the spirits into it. But of such *hypotheses*, without either proof or probability, there can be no end.

DURING the *diastole* of the heart, all its coronary vessels, which were in a great measure emptied by the preceeding *systole*,

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are filled with blood violently pushed into them by the contraction of the *aorta* : but as the arterial blood is not immediately necessary to the contraction of a muscle *, and seems only to contribute to it in a secondary way, this alone will be thought far from being sufficient to account for the succeeding *systole* of the heart. 'Tis true indeed that warm water, injected into the arteries of an animal newly dead, excites some kind of motion in the muscles, to which these arteries are distributed. But this contraction is so weak and so unlike that of the heart, that I persuade myself, hardly any one, will, from this experiment alone, imagine the *systole* of the heart, to be owing to the arterial blood pushed forcibly through all its vessels, in the time of its *diastole* ; especially since we do not observe the least degree of an alternate motion in the sphincters of the *anus* and bladder, from the blood being more strongly impelled through their vessels, upon every contraction of the heart, than during its *diastole*. This matter however is put entirely beyond dispute, by the heart's continuing to repeat its contractions,

* Sect. 1. No 2. of this Essay.

contractions, not only after the coronary arteries, and pulmonary veins are tied, but after it is separated from the body.—The blood then with which the coronary vessels of the heart are filled during its *diastole*, being as insufficient as is the supposed compression of the cardiac nerves, to account for its succeeding *systole*; it remains, that we next inquire, what influence the returning venous blood, with which the ventricles of the heart are distended during its *diastole*, may have in producing its subsequent *systole*. And is it not reasonable to suppose, that this fluid returning by the *cavæ* and pulmonary veins, and rushing into the cavities of the heart, with a considerable force, must by distracting its fibres, as well as by its motion and attrition upon the scabrous surface and fleshy pillars of the ventricles, so stimulate and affect the sensible nerves of the heart, as to bring it immediately into contraction *?

THOUGH some authors have long since ascribed the alternate motion of the heart, to the irritation of the blood received by
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* Sect. I. N^o 8. 9. &c.

turns into its cavities* ; yet as this cause has been much overlooked by many late writers, and not rightly understood by some others, we shall endeavour to confirm, and illustrate the manner of its influence, by a variety of arguments.

WHILE some authors have ascribed the contraction of the heart solely to the blood, considered as a stimulating fluid, which irritates the internal surface of its ventricles ; others have been unwilling to allow, that the blood acts in any other sense as a *stimulus*, upon the heart, than as by its weight and impulsive force it stretches and extends the fibres composing its ventricles†. But the increased motion of the blood, from the contagion of the small pox, measles, &c. and after eating or drinking any thing acrid,

as

* Certumque est, vesiculam dictam, ut et cordis auriculam postea, (unde pulsatio primum incipit) a distendente sanguine, ad constrictionis motum irritari. *Harvey* de general. animal. exercit. 51.

Fibræ cordis virtute micationis vitalis sanguinis in ejus ventriculis contenti, per vices IRRITATAE, excitantur ad se contrahendas et pulsationem faciunt, mox IRRITATIONE remissa relaxantur. *Glisson* de ventricul. et intestin. cap. 7. p. 170.

† *Senac.* traité du COEUR, lib. 2. cap. 4. sect. 4.

as well as the power which acrid or stimulating substances have in renewing the heart's motion after it is separated from the body, are circumstances which shew, that the contraction of the heart is not solely owing to its fibres being distracted by the moment of the blood, but partly to the irritation communicated to its internal surface by the particles of that fluid. And the remarkable diminution of the peristaltic motion of the bowels, when the cystic bile is hindered from flowing into them, makes it evident that the stretching of the fibres of the intestines, by the air and aliment contained in them, is not the sole cause of their succeeding contraction. On the other hand, the increase of the heart's motion from exercise, or from any other cause, whence the blood is returned in greater quantity, and with more force; its diminution by blood-letting, the *phænomena* of the motion of the stomach, and of the expulsion of the urine and *feces* *; all these particulars, I say, prove, that even the distension of hollow muscles has, a remarkable

* See sect. 5. below.

able influence towards exciting them into action *.

FARTHER, that the blood is extremely well fitted, to act upon the heart as a *stimulus*, in both these ways, will appear, if we consider its composition, heat, intestine motion, what some authors have supposed it to receive from the air, and the force with which it rushes into the cavities of the heart.

1. As to its composition. The blood consists of the same principles with our aliments, and consequently abounds with salts and oils. The salts of the blood are partly of the fixed neutral kind, and partly rendered as it were semivolatile by the heat and motion to which they are subjected; both are extremely apt to irritate very sensible nervous parts; for we know that any kind of salt applied to the eye gives remarkable uneasiness.—The oils in the blood are either those of animal substances, the expressed oil of vegetables, their attenuated oil by fermentation, commonly called *alcohol*, or lastly the acrid oil of aromatics. The two first are

* See sect. 1. N° 8. above.

are no ways acrid or fit to act as a *stimulus*, unless they have been highly attenuated by long exposure to heat, or by attrition ; the two latter, *viz.* ardent spirits and the oil of aromatics are very apt to irritate the tender fibres of living animals. Hence it is that spirituous liquors largely drunk and hot spices too freely used, quickly raise the pulse, and make the heart as it were redouble its contractions. Hence eating animal food or drinking strong liquors, which abound with saline and acrid particles, remarkably quickens the circulation, and increases the heat of the body, while a dinner of milk, mild herbs, or cooling fruits, makes little alteration in the pulse. The blood therefore as it is impregnated with salts and attenuated acrid oils, must be very well fitted to communicate a gentle *stimulus* to those sensible nerves which terminate on the internal surface of the auricles and ventricles of the heart.

IF it be objected, that the blood discovers no acrimony to the tongue, nor sensibly irritates the eye ; it may be sufficient to answer, that, though this fluid be remarkably
salt

salt to the taste, yet I do not ascribe the whole stimulating power of the blood to its acrid particles alone, but to these in conjunction with several other qualities and circumstances just now to be considered. But further, although the blood did not discover the least degree of acrimony when applied to the nerves of the tongue (which however is not the case), yet it might be well fitted to act as a *stimulus* upon other nerves of the body, differing from these in their constitution and peculiar sensibility.— Many poisons, especially of the antimonial kind, are void of almost any degree of acrimony, as far as we can judge by the taste; yet they so strongly and disagreeably affect the nerves of the stomach, as to bring this organ, together with the neighbouring parts, into violent convulsions, and produce a train of the most direful symptoms; by which all the functions of the animal frame are greatly disordered, interrupted or finally stopt. The roots of the *cicuta aquatica* are sweetish, but neither acrid nor disagreeable; and cataplasms of them applied to inflamed or ulcerated parts, occasion no bad symp-

symptoms* ; yet, when taken into the stomach, they soon throw the whole body into the most terrible convulsions, which generally end in death.—The berries of the *rhus myrtifolia monspeliaca*, though there be nothing in their taste or smell to render them suspected, yet act so powerfully upon the nerves of the stomach, when swallowed, that, in half an hour after, they bring on an epilepsy, whose repeated attacks kill the patient in less than 24 hours†. — Viper's poison affects neither the nerves of the tongue nor stomach with any disagreeable sensation ; yet the smallest drop of it received by a wound into the blood, seems not only to act as a ferment upon this fluid, but, by its stimulating quality, to affect most violently the whole nervous and vascular systems.—The putrid excrement which gives no disturbance to the *colon* or *rectum*, till by its quantity it overstretchers their fibres, would create sickness and vomiting in the stomach.—Urine which scarce stimulates the bladder till it begins to distend

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* *Wepferi historia cicut. aquat.* p. 84.

† *Memoires acad. sciences* 1739. edit. 8vo, p. 627.

tend it too much, proves a good purgative clyster, when it is injected into the great guts.—Warm blood received into the stomach by a rupture of any of its vessels, proves very ungrateful to its nerves, but does not affect the nerves of the heart or arterial system with any disagreeable sensation.—Every one knows what remarkable changes happen in the body about the time of puberty : these changes are generally, and not without reason, ascribed to the *semen* which now begins to be duly prepared : they do not, however, seem to be owing so much to the reception of the finer parts of this fluid into the blood, as to its peculiar action upon the nerves of the *testes* and *vesiculæ seminales* ; yet the *semen*, when applied to the nerves of other parts of the body, neither sensibly titillates them, nor produces any remarkable effects.

THUS it appears from a variety of examples, that the nerves of different organs in the same animals are so constituted, as to be very differently affected even by the same things : So that we cannot absolutely take upon ourselves to judge, by our taste or smell,

smell, how far any liquor may or may not be adapted to act as a *stimulus* upon the nerves of a particular organ ; and, consequently, that although the blood scarce irritates sensibly the eyes or tongue, it may nevertheless so stimulate the nervous *papillæ* of the heart, as to excite this muscle into contraction : which will further appear, if we consider the heat of this fluid.

2. HEAT seems to be no more than a violent vibration or motion in the smaller parts of bodies ; therefore the blood, as it is a warm fluid, must have its particles agitated by perpetual vibrations, which must be communicated to the nervous *papillæ* on the internal surface of the heart : besides, as the blood abounds with oily and sulphureous particles, it must, by its motion and attrition against the vessels, acquire vibrations still more remarkable.

BECAUSE in fishes and frogs, whose hearts retain their moving power very long, the blood is but a very little warmer than the water in which they swim, it has been said, that the stimulating quality of the
blood

blood cannot be any ways owing to its heat; but a little reflexion will shew how ill founded this assertion is.

It will not be denied that a certain degree of heat is necessary to the continuance of the motion of the heart in those animals whose blood is warm; and the same thing is not less true of frogs and fishes, whose blood is not really cold, although it may be said to be so, when compared with that fluid in men and many other animals. As a proof of this, not only bats, hedgehogs and most of the insect tribe remain, in northern countries, in a torpid state during the cold season of winter, but the same thing happens to frogs and other animals, whose blood is but very little warmer than the air or water which surrounds them. The motion of the heart, however, even in these animals, may be at any time, renewed, and the circulation of the blood and life may be restored, by exposing them to an equal or greater heat, than that which prevails in the summer season; from which it follows, that a certain degree of heat is necessary, even in the coldest animals, to the continuance

nuance of the motion of the heart: and as a further proof of this, when the hearts of frogs and fishes, after being separated from their bodies, begin to move more languidly, they acquire new vigour by being exposed to the heat of a fire, or even to the sun-beams in a hot summer's day.

THE truth is, that there is no absolute cold, but only different degrees of heat; and blood whose heat does not exceed the fortieth or fiftieth degree in *Fahrenheit's* scale *, may be as fit to stimulate the heart in certain animals, as the much hotter blood of men and quadrupeds may be, to continue the motion of that organ in them. And indeed, the very remarkable effect which heat has in exciting the hearts of animals into alternate contractions, and thus promoting the circulation of their fluids, is too well known, to admit of any doubt. By different degrees of warmth or cold, insects
and

* It is to be observed, that although, in northern climates, the surface of the sea is often colder than fresh water when it begins to freeze, and consequently would make *Fahrenheit's* thermometer fall under thirty-two degrees, yet at any considerable depth, and where fishes generally live, the sea is not much colder in winter than in summer.

and the chick in the shell, may at pleasure be made more or less lively, consigned to death or restored to life *.

3. THE particles of the blood, besides the oscillations they are put into by heat, are agitated by a motion of another kind. As vegetables make up the chief part of our aliment, the chyle is generally acceſcent ; yet the blood and other perfectly elaborated animal juices are of a contrary nature, ever tending to putrefaction, and when treated by the fire, afford a volatile instead of a fixed alkaline salt : such a change in the nature of the chyle, could not be produced without an intestine motion of its particles ; which we find to be the grand instrument of nature in changing the texture and dispositions of all vegetable and animal bodies †.

This

* Vid. *Harvey* de motu cordis, cap. 17. de generatione animal. exercitat. 17. et *Reaumur*. histoire des insectes. tom. 2. memoire 1.

† It is as unreasonable to deny any degree of intestine motion in the fluids of animals, because this is not perceived by our senses, as it would be to argue against their being possessed of any degree of heat, because we are not sensible of
their

This intestine motion added to the vibrations of the particles of the blood from heat, will still better qualify it for acting as a *stimulus* upon the extremely sensible and tender nerves of the heart.

4. SIR *Isaac Newton* imagined, that the beating of the heart was continued by an acid vapour in the air, received into the blood by means of respiration * ; in which opinion he has been followed by Dr. *Robinson* † and others. But although particular regard is to be paid even to the hints and conjectures of so great a man, especially of one, who was no less remarkable for his caution in advancing *hypotheses*, than for his deep knowledge of nature, yet the love of truth is ever to be preferred to the greatest names.

The
their warmth when moving through our vessels. A fluid, such as the blood, composed of various and disagreeing particles, whose attractive and repulsive powers are very different, and upon which the same degrees of heat and friction must have different effects, cannot fail, by its rapid motion, to have its globules and their constituent parts agitated with brisk vibrations.

* Optics, edit. 8vo, p. 355.

† Treatise on the animal œconomy, prop. 24.

The opinion of Sir *Isaac Newton* as well as other Philosophers, who imagined that fresh air was necessary to preserve the life of animals, on account of some *pabulum* or vivifying spirit which it contains, seems to have taken its rise from the death of such animals as were confined in a close vessel, and consequently were obliged, for a long time, to breathe the same air. But this fact is not a sufficient proof of that opinion: and were it not foreign to my present purpose, I could bring very strong arguments to shew that the death of animals in air that is not renewed, is not owing to the consumption of any vivifying spirit or *pabulum vite*, which it has been supposed to contain, but to the vapours exhaling from the bodies and particularly from the lungs of those animals; which soon acquire such a putrid acrimony, as to become as much a real poison to the nerves of the bronchial tubes and pulmonary vesicles, as is the vapour of the *grotta de cani* in *Italy*, the damp of subterraneous places, or the steams of burning charcoal.

5. A body, whether fluid or solid, of a nature which qualifies it to act as a *stimulus*, will excite so much the stronger irritations, by how much greater the force is with which it is applied to the sensible part; since its acute, acrid, or otherwise active particles, must by this means strike more strongly against the extremities of the tender nerves. Hence the blood, which we have shewn to be well fitted for gently irritating the sensible membranes of the cavities of the heart, must, by its being pushed into them with a considerable force, act with so much the greater energy. But further, as by the blood rushing impetuously into the auricles and ventricles of the heart, these cavities are dilated beyond their natural capacity, so the extension which their fibres must suffer on this occasion, cannot fail to produce some sort of irritation, and thus prove a *stimulus* to their subsequent contraction*. Agreeably to this, *Wepferus* has

I observed,

* It here deserves particular notice, that while the ventricles of the heart are extended much beyond their natural size, by the force of the reflux venous blood, the tendineo-carnous chords which often run from one side of the ventricles

observed, that after one vermicular contraction of the stomach is performed, another does not succeed, till this organ begins to be remarkably swelled, in its middle part, by the rarified air contained in it, or generated by the dissolving aliments: But this distension of the stomach no sooner happens, than a new contraction of it begins, which proceeding on towards the *pylorus*, expells part of that air, and of the digested aliment into the *duodenum*; after which this orifice collapses, and a new intumescence of the stomach quickly ensues*. Hence it appears how great an analogy there is, between the causes of the alternate contraction of the heart and stomach; both being excited, partly by the distraction of their fibres by a distending cause, and partly by the irritation of their sensible nerves by a stimulating one.

to the other†, must be considerably stretched; which cannot fail to produce an irritation in these parts, and consequently to contribute towards exciting the succeeding *systole* of the heart.

† Vid. *Cowper's myotom. reformat.* tab. 39. let. h. et tab. 40. let. f. also *Senac. Traité du coeur.* vol. 1.

* *Wepferus* de cicut. aquat. p. 177.

one. In like manner the contraction of the bladder of urine, and the desire of evacuating this fluid, is not only owing to its acrimony stimulating the nerves of the bladder, but also to its quantity overstretching the coats, and distracting the fibres of this organ.

UPON the whole, from what has been said, it may appear, that as the violent motion of the fluids, and uncommon contractions of the heart and arteries in the small pox, measles and other feverish diseases, is in a great measure owing to some foreign particles mixed with the blood, whence it stimulates their nerves more strongly; so the ordinary and less violent motion of the heart, is owing to the gentler *stimulus* of the fluids in a sound state.

FURTHER, that the alternate contractions of the heart are excited in the manner above explained, a variety of other arguments concur to shew.

1. THE quickness and strength of the heart's motion are, *ceteris paribus*, always proportional to the force with which the venous

venous blood returns to its ventricles by the *venæ cavæ* and pulmonary veins: hence exercise of any kind accelerates the motion of the heart, and increases the force with which it contracts: a fit of laughter will quicken the pulse above twenty beats in a minute*: upon an intermission of respiration, the pulse becomes smaller, but recovers its former strength immediately after repeating it again†.

2. It appears from Dr. Hales's experiments, that the blood returns to the heart by the two *venæ cavæ* with nearly $\frac{1}{10}$ of the force with which it was pushed into the *aorta*; and as the left ventricle of the heart is at least three times stronger than the right, the returning venous blood will endeavour to dilate the right ventricle with a force nearly equal to $\frac{1}{3}$ of the power with which it usually contracts in the time of its *systole*; and this even without, taking into the computation, the additional *impetus* communicated to the blood by the contraction of
of

* *Robinson* on the animal œconomy, prop. 21.

† *Ibid.* prop. 24.

of the right auricle: but, by violent straining, the force of the blood in the veins is often rendered above four times greater than ordinary*, and consequently superior to that with which the right ventricle contracts when the body is at rest: wherefore, if we do not allow the strength with which the ventricles of the heart contract, to depend in a great measure upon the action of the venous blood on them, it will be difficult to conceive how the right ventricle should be able to overcome the force with which the blood rushes into it, upon any straining or violent exercise, and in horses running at full speed. Moreover, it is evident, from the state of the pulse in peripneumonies, both before and after bleeding, as also from the remarkable increase of the force of the blood in the *aorta* and its branches after deep sighing†, that the strength with which the left ventricle of the heart contracts, is immediately increased or diminished, according as the blood is squeezed

* *Hales's statical Essays*, vol. 2. p. 14. and 161.

† *Hales's statical Essays*, vol. 2. p. 6. and 16.

ed with more or less force through the pulmonary veins into its cavity.

3. IT is very observable, that the auricles and ventricles of the heart are no sooner filled with the reflux blood, than they immediately begin to contract ; which strongly indicates the influx of this fluid to be the cause exciting their subsequent contraction. In dying animals, those cavities of the heart cease from motion first, which are first deprived of the returning venous blood: hence a little before death, when the blood is not pushed by the force of the right ventricle beyond the capillary arteries of the lungs, the left ventricle being deprived of its *stimulus*, is observed first of all to cease from motion, and soon after it the left auricle : but the right ventricle, being still supplied with blood from the two *cavæ*, continues its motions for some considerable time ; and, even after it seems to die, the alternate motions of the right auricle are kept up by the small stream of blood which flows into it from the *venæ cavæ*. This, however, is not sufficient to actuate the right ventricle, till after several contractions
of

of its auricle, more blood being collected in it, it begins anew to tremble, and, as it were with some struggle and difficulty, slowly performs another contraction*. After both the right ventricle and auricle have wholly lost their motion, the right *sinus venosus* continues for some little time gently to palpitate, and its tremulous motion, when about to cease, may, like that of the heart, be renewed by heat, or any thing else that is capable to irritate its fibres†. After this right *sinus venosus* has also ceased to move, the trunks of the *venæ cavæ* adjoining to it continue, for a considerable time, to be alternately contracted and relaxed. When the *vena cava inferior* is tied, and the blood

is

* After cutting away the *venæ cavæ*, opening the pulmonary artery and emptying the right ventricle of the heart of all the blood contained in it, M. De Haller tied the *aorta*, by which means, the left ventricle and auricle were kept full of blood. He then observed the right auricle to remain at rest, while the right ventricle was affected with a feeble palpitation in consequence of its sympathy with the left one: But the left auricle beat strongly for some time, and the left ventricle continued its alternate motions for near two hours. See Act. Gottingenf. vol. 1.

† Harvey de motu cord. cap. 4. & Waleus de motu chyli & sang. epist. 1. ad fin. Bartholin. anat. p. 783. & 784.

is squeezed out of that portion of it which is between the ligature and the heart, its motion immediately ceases, but begins again, as soon as the ligature is removed and new blood is allowed to flow through that vein. Lastly, after both the *venæ cavæ* of a rabbit were tied, and the blood contained in them and the heart, was evacuated by a hole made in the substance of this organ; its motions, as well as those of its auricles, and the trunks of the *venæ cavæ*, ceased at once, but were renewed upon the ligatures being taken away*.

DR. *Langrish* tells us, that in a dog whose *thorax* he opened, and whose lungs he kept playing with a pair of bellows, the auricles began the motion, and the *systole* of the ventricles always instantly followed that of the auricles. When he desisted from blowing fresh air into the lungs, the heart lay still, but recovered its motion when the lungs were strongly distended anew. In this action, he never could discover that the ventricles began the motion, but the auricles

* See Bartholin. epistol. anatom. cent. iv. p. 111. & 112.

ricles always contracted first, and immediately after them the ventricles ; though at last he observed several contractions of the auricles which were not succeeded by any motion in the ventricles *. From what has been said, it plainly appears, why the motions of the auricles and ventricles are not synchronous, *viz.* because they receive into their cavities at different times the returning blood, which, as a *stimulus*, excites them into contraction.

4. PEOPLE frequently recover from a *leipothymia* and *syncope* as it were spontaneously, and without any external assistance, because the chyle and lymph continue, by means of the peristaltic motion of the guts, to be forwarded to the subclavian vein and *cava* ; at the same time that the venous blood, partly by the contractile power of the greater arteries, and the oscillatory motions of the smaller ones, and partly by the constriction of the cutaneous vessels from cold, is transmitted into the branches of the two *venæ cavæ*, and forwarded to the right

K

auricle

* Cronean lectures on muscular motion, p. 61, 62.

auricle of the heart, which it first stimulates into contraction ; and immediately afterwards sets the right ventricle also a going. Nay many people who have been dead in appearance, have been restored to life by blowing air into their lungs, and thus communicating a new motion to the stagnating blood in the *cava inferior* and pulmonary veins. Of this we have a remarkable instance recorded in the *Edinburgh Medical Essays*, vol. 5. art. 55. ; where we are told, that a man was brought to life, by distending his lungs with air, and putting the blood in the pulmonary veins and left. *sinus venosus* into motion, after his heart had remained at rest for at least half an hour* : and that it was in this way that the blowing into his lungs recovered him, is evident ; since no sooner were the lungs thus dilated, than immediately the heart began to move, and six or seven very quick beats were felt below his left breast ; after this, the lungs continuing of themselves to play, a pulse

was

* The inflation of the lungs, by pressing the *vena cava inferior*, must also have communicated a motion to the blood in the right *sinus venosus*.

was soon perceived in the arteries. Hence it appears, that, in order to set the heart a going, and restore life in animals which are not irrecoverably dead, it is only necessary to communicate such a motion to the blood in the *cava* or pulmonary veins, as may enable it a little to dilate the auricles and ventricles of this muscle.

5. THE heart after it has ceased to move, is not only set a going again by determining the venous blood into its cavities, but, in animals which have been for some time dead, its motion may be renewed by blowing air through the thoracic duct or *vena cava* into its right auricle and ventricle, or through the *aorta* into its left ventricle. Thus, while *Peyerus* was endeavouring to distend the *receptaculum chyli* and thoracic duct with air, the heart was not only rendered turgid by this fluid which had made its way into it, but immediately began to vibrate, and continued its motions for several hours*. The same experiment was afterwards

* *Peyeri parerg.* 7. p. 199. and *Wepfer. de cicut. aquat.* p. 89.

afterwards repeated by *Brunnerus* on a dog with equal success *. And *Harderus* relates that in a stork, which had been killed by poison, he made the heart renew its motion, by blowing air into the *aorta* †. Since, in these experiments, and in others which might be recited from other authors, the heart, which had lain quiet, and without any motion for a considerable time after death, was readily excited into contraction by the air stretching its fibres, and probably stimulating its nervous *papillæ*; and since the heart, as we are told by Dr. *Harvey*, and as I have often experienced, after it has ceased to move in an animal newly killed, may be again put in motion, by applying to it a little warm *saliva* ‡; we need not be at a loss to account for the alternate motions of that

* Experiment. circa pancreas, p. 21.

† Additamenti ad *Peyeri* parerg. 7. p. 201.

‡ In columba certe experimento facto, postquam cor desierat omnino moveri, et nunc etiam auriculæ motum reliquerant per aliquid spatium, digitum saliva madefactum, et calidum cordi superimpositum detinui: hoc fomento quasi vires et vitam postliminio recuperasset, cor, et ejus auriculæ, moveri et sese contrahere atque laxare, et quasi ab orco revocari videbantur. *Harv. de motu. cord. cap. 4.*

that organ in living animals, where, a warm active fluid is alternately pushed into its cavities.

THERE is only one objection, which at present occurs, to the above account of the heart's contraction, *viz.* that its alternate motions may be owing to some peculiar power resulting from the structure and constitution of its fibres, and that by virtue of this, it is enabled to continue these motions long after the blood has ceased to act upon it. In answer to which, it is sufficient to observe, that in dead animals in whom the motion of the blood is stopt, the heart remains at rest till its vibrations are renewed by exposing it to the open air, or by otherwise stimulating it * : whatever power therefore, may be supposed to reside in the fibres of the heart, a *stimulus* of one kind or other is always necessary to excite it into action. In living animals this *stimulus* is, as we have shewn, no other than the returning venous blood : in animals newly dead, warm water, air, and a variety of other *stimuli* excite into action this power which

seems

* Sect. xiv. below.

seems to reside in the fibres of the heart ; which, whether it is owing merely to their mechanical structure, to the animal spirits lodged in them, or to some other cause, will more fully appear in the sequel of this Essay.

S E C T. IV.

Of the relaxation and diastole of the heart.

HAVING shewn that the *systole* of the heart is owing to the returning venous blood acting upon its auricles and ventricles as a *stimulus*, it remains that we next inquire in what manner its relaxation and *diastole* are brought about.

THE ventricles of the heart having, by their contraction, expelled the blood contained in them, into the *aorta* and pulmonary arteries, are immediately after relaxed ; their fibres losing that tension and firmness which they had the moment before. This relaxation of the heart must necessarily follow its *systole*, since the muscles of living animals, after being

being excited into contraction by any *stimulus* applied to them, are quickly relaxed again *. What may be the reason of this *phenomenon* we shall not now inquire, but refer it to be afterwards discussed in a more proper place †; it being sufficient for our present purpose that the thing is allowed to be true. Only we may observe with respect to the heart, that as the stimulating cause (*viz.* the blood) is, during the *systole*, expelled out of its cavities, it is reasonable to think that the fibres of this muscle which were in a violent state, will of themselves endeavour to return to their most natural condition ‡.

THE

* Sect. i. N^o 10. and 11. above.

† Sect. x. below.

‡ Dr. *Langrish* is of opinion, that when the heart is in *systole*, some of its fibres are always stretched out beyond their natural tone; so that by their elastic restitutive property, they act in a certain degree as antagonists to the contracted fibres, and so contribute to unbend them at the end of every *systole*. *Cronean lectures*, p. 55. But whatever may be in this, it does not appear that the heart is, by any thing in its make, better fitted to relax itself, than the other muscles; since these, or even a few of their fibres, when separated from the body, and so deprived of their antagonists, are observed to be alternately contracted and relaxed like the heart. Vid. Sect. xiv. below.

THE ventricles of the heart, in consequence of the relaxation, which happens to their fibres after their *systole* is finished, give no resistance to any cause that begins to dilate them; but will not, without violence, allow their sides to be removed from each other, so much as happens during their *diastole*.

From Dr. *Hales and Langrish's* experiments compared, it appears that the capacity of the left ventricle of an ox's heart, in consequence of the natural relaxation of its fibres, is to its capacity, when fully dilated by the refluent blood, nearly as 1 to $2\frac{1}{2}$ *. As therefore the relaxation of the heart at the end of every *systole*, is owing to the contraction of its fibres ceasing at that time; so its full *diastole* is produced by the returning venous blood, which enters its cavities with a very considerable force. Without this, it is impossible that any relaxation of the heart could produce its *diastole*; since a hollow muscle, such as the heart or bladder of urine, can never be fully dilated by means of its own internal mechanism, or without the

* Vid. *Hales's* statical essays, vol. 2. p. 25. & *Langrish's* Cronean lectures, No. 147.

the assistance of a distending cause introduced into its cavities. But although the *diastole*, or full dilatation of the ventricles of the heart, must necessarily be ascribed to the force of the refluent blood ; yet this alone, without a preceding relaxation of their fibres, would be insufficient to produce that effect.

'Tis true indeed, that the contraction of the auricles, and the *momentum* of the refluent blood, are, in some sense, antagonists to the ventricles * ; but both these taken together, falling much short of the force with which the ventricles contract, there must necessarily be some other cause, which relaxes the fibres of the heart, and renders them as it were paralytic at the end of every *systole*. Besides this, the flaccid appearance of this

L muscle,

* It is a mistake to think, that no blood is pushed into the ventricles of the heart during their *diastole*, except what was contained in the auricles properly so called. A certain quantity of blood from the *sinus venosi* also enters them, without being previously received into the auricles: of this the smallness of the left auricle alone is a demonstration. We are therefore to conceive of the blood during the *diastole* of the heart, as rushing into its ventricles, both from the auricles and *sinus venosi*, and with the united force arising from its *momentum* in the veins and from the contractile power of these hollow muscles.

muscle, immediately after its contraction is finished, and before its ventricles are filled with blood, demonstrates beyond all doubt, that its fibres are then in a state of relaxation.

WHAT has been just now said of the relaxation and *diastole* of the ventricles of the heart, is so applicable to its auricles, that it would be quite superfluous to say any thing of their dilatation.

WE have already observed *, that the force with which the ventricles of the heart contract, is, *cæteris paribus*, always proportional to the *momentum* with which the blood flows into them, or, in other words, to the cause dilating them : the *systole* of the ventricles will therefore be, *cæteris paribus*, always proportional to their preceding *diastole* ; and hence it is that a full pulse strikes the finger with so much greater force than a small one.

As the left ventricle of the heart must, on account of its superior strength, require a greater force to complete its *diastole* than the right ventricle, the blood ought to return to it with a greater *momentum* ; and that it really does so, will, I presume, evidently appear

* Sect. iii.

appear from what follows. — The force with which the blood returns to the right ventricle of the heart by the two *venæ cavæ*, is in animals at rest and not agitated with convulsions, according to Dr *Hales's* experiments, nearly equal to $\frac{1}{10}$ of the force with which it was pushed by the left ventricle into the *aorta**; *i. e.* in a man of an ordinary size, it acts in dilating the right ventricle with a force equal to the pressure of a column of blood whose height is between 8 and 9 inches, and whose base is equal to the internal surface of that ventricle, *i. e.* with a force equal to the pressure of about five pounds †. — The force with which the blood returns by the pulmonary veins to the left ventricle of the heart, is not so easily determined; but that it must be very considerable, is evident, from the pressure of the air upon the vessels of the lungs in respiration; the precise force of which as it is

* M. *Sauvages* has computed the virtual velocity or *momentum* of the blood in the iliac artery of a dog, to be at least twelve times greater than in its corresponding vein. See *Histoire Acad. de Berlin*, 1755.

† *Hales's* statical essays, vol. 2. p. 40.

is difficult to investigate, so it is not to be wondered, that several learned men who have attempted it, should have fallen into mistakes. It seems, however, demonstrable, from an experiment of *John Bernouilli*, that when one endeavours to expire with all his might, the whole surface of all the vesicles of the lungs may sustain a pressure equal to 420 lib. weight*. But as this can only happen upon the most violent straining, it is of little use to determine the pressure of the air upon the lungs, in ordinary respiration; which must bear a very small proportion to this, and is not only different in different persons, according to the ease with which they breathe, but vastly different in the same persons at different times: and although the pressure of the air upon any particular portion of the lungs must appear to be small in ordinary respiration, if we consider how softly, and with what ease this action is carried on, yet the pressure upon the whole internal surface of all the pulmonary vesicles may be very considerable. Thus, if the force of the air rushing

* *Michellot. de separatione fluidor. p. 181.*

ing out at the aperture of the *glottis* in ordinary expiration, be supposed equal to the pressure of 2 grains, (which is far from being an extravagant demand), then, since fluids press equally on all sides, every portion of the internal surface of the lungs of the same dimension with the aperture of the *glottis*, *i. e.* every $\frac{1}{8}$ of a square inch of their surface (for the aperture of the *glottis* does not exceed this) must sustain, at that time, a pressure from the air equal to 2 grains; wherefore, supposing the sum of the surface of all the vesicles of the lungs in a man to be 20,000 square inches, it must, in ordinary expiration, sustain a pressure equal to 320,000 grains, or 666 ounces*. If to this force alternately pressing on the lungs, we add the *momentum* which the blood in the pulmonary vessels receives from the contraction of the right ventricle of the heart, it will appear highly probable, that
this

* Dr. *Keil* has estimated the sum of the surface of all the vesicles in the human lungs to be 21906 square inches; which computation is in Dr. *Hales's* opinion too low, who has determined this surface in a calf to be 40,000 square inches. *Hales's* statical essays, vol. 1. p. 242

this fluid returns, by the pulmonary veins, to the left ventricle with a much greater force, than it did to the right one by the two *venæ cavæ*.

BUT, to put this matter beyond all doubt, we need only compare the capacities of the two *venæ cavæ* and pulmonary veins. According to the measures of the accurate *Santorini*, the *area* of the transverse sections of the two *venæ cavæ*, is to that of the pulmonary veins, nearly as 3 to 2*. Now the *momentum* of the blood in these different vessels, must be as the transverse section of the vessels multiplied into the squares of the velocities: but since equal quantities of blood pass through them in equal times, the velocities must be inversely as the sum of the transverse sections; therefore (by compounding *ratio's*) the *momenta* will be inversely as the sum of the same transverse sections, *i. e.* the *momentum* of the blood in the *cavæ*, taking *Santorini's* measures for a standard, is to its *momentum*, in the large trunks of the pulmonary veins, as 2 to 3: and this upon the supposition that the resistance to the blood's motion in the *cavæ* and pulmonary veins were equal; which
however

* *Observat. anatom.* p. 145.

however is not the case, since the left ventricle of the heart must require a greater force to complete its *diastole* than the right one, and consequently give a greater resistance to the blood flowing into it from the pulmonary veins, than the right ventricle does to the blood in the *cavæ*. Supposing therefore, with *Santorini*, that the capacities of the *cavæ* and pulmonary veins are generally as 3 to 2, the *momentum* of the blood in the latter, will exceed its *momentum* in the former, in a proportion somewhat greater than that of 3 to 2.

M. *Helvetius*, it is true, has drawn a different conclusion from the small capacity of the pulmonary veins, when compared with that of the *venæ cavæ*, or pulmonary artery *, *viz.* that the blood is denser in the former

* The sum of the transverse areas of the pulmonary veins, is not only less than that of the two *cavæ*, but also less than the sum of the transverse areas of the branches of the pulmonary artery, contrary to what is observed almost every where else in the body. It has been warmly disputed, whether this discovery was first made by *Helvetius* or *Winslow*, or if it does not rather belong to Dr. *Drake*, who has painted the branches of the pulmonary artery larger and more numerous than

former than in the latter, but not that its velocity is greater †: and this density, he imagines, it acquires chiefly by being exposed to the cool air, in its passage through the small vessels of the lungs. In answer to which, it is sufficient for our purpose to observe, that unless the blood is condensed in the lungs into $\frac{2}{3}$ of its former bulk, (a supposition which cannot be admitted) it must needs flow through the pulmonary veins, with a greater velocity, and consequently with a greater *momentum*, than thro' the two *cavæ*. The small expansion and

conden-

than those of the veins, (Anat. tab. 12. and 13.); although he says nothing of this inequality either in his description of the lungs, or in his explication of these figures. This debate, of no great importance indeed, might have been easily decided, if the persons concerned in it, had looked into the proem of Dr. *Harvey's* book *de motu cordis*, &c.; where we find the following passage; from which it appears, that this speciality in the pulmonary veins was not unknown to that illustrious author. “ Quum venam arteriosam, vas amplum magnum cum tunica arteriæ factum, non nisi privato et uni usui, (viz. alendis pulmonibus) destinariint: cur arteriam venalem vix pari magnitudine cum tunica venæ molli, laxa, pluribus usibus, tribus vel quatuor videlicet, fabrefactam esse asseverant ? ”

† Memoires acad. des sciences 1718. edit. 8vo, p. 281. &c.

condensation of water, oil, spirit of wine, and other liquors in thermometers, arising from considerable degrees of heat and cold, shew, that the cool air applied to the surface of the lungs, can have but little influence in condensing the blood; besides, it seems not at all improbable, that the blood may acquire a heat in the lungs, sufficient to compensate the refrigeration it is there exposed to. It is generally thought, and indeed not without good reason, that the blood in the pulmonary veins is somewhat denser than in the artery of that name: but this, perhaps, is not so much to be ascribed to the coldness of the inspired air, as to its pressure, and to the action of the elastic vessels of the lungs.

IF it be objected to what we have offered in proof of the blood's returning with greater force to the left, than to the right ventricle of the heart, That in a *fœtus in utero* this seems not to be the case; it may be answered, that the strength of the left ventricle in a *fœtus*, exceeds that of the right but little; or, at least, not near so much as in adult animals:— that the right

ventricle not only pushes part of the blood through the vessels of the lungs, but also distributes a good deal more than $\frac{1}{3}$ of the whole mass to the *aorta* and its branches:—that the force of the blood returning by the two *cavæ* to the right ventricle is greatly lessened, by its having a free passage thro' the *foramen ovale* into the left *sinus venosus*; while the blood by this means enters the left ventricle, not only with the force with which it returns from the lungs, but also with a great part of that with which it flows in the *cavæ*.

IN speaking of the force with which the blood returns to the two ventricles of the heart, we have taken no notice of the additional *impetus* communicated to it, by the contractions of the auricles and *sinus venosi*, because this is common to both ventricles; although it must be confessed, that the left auricle seems to be weaker, as well as less capacious than the right; and perhaps it was so formed, as the blood returning with great impetuosity from the lungs, after having been intimately mixed and elaborated there, may not require so large an auricle, as the

venous

venous blood of the *cave*, which moves with less force, and is composed of parts less perfectly united.

UPON the whole, if it shall be asked, why the heart being a solitary muscle, and destitute of any antagonist, does not, like the sphincters, always remain equally contracted; the answer is obvious, *viz.* that muscles brought into action by a *stimulus*, are immediately relaxed again*; which relaxation therefore happening to the heart, the blood, in its return, enters the ventricles with considerable force, and, by dilating them, acts in some respect as antagonist muscles do in other parts of the body; at the same time that, by its gentle irritation, it is the cause of their subsequent contraction. The heart must of necessity, therefore, be alternately dilated and contracted, as long as the returning blood continues to be poured into its cavities†: nay, since the contractions of muscles from a *stimulus* are alternately repeated both in living and newly dead animals, although the *stimulus* is not renewed after every

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* Sect. 1. N^o 10.

† Sect. 1. N^o 12, 13, and 14.

ry contraction*, and since the heart continues to vibrate for some time after injecting warm water or air into its cavities, it is highly probable, that the irritation of the returning blood in a sound state, is capable of making it perform not only one, but several contractions; which seems to be confirmed by the heart's palpitating after the *vena cava* and pulmonary veins have been tied, and consequently after the blood is intercepted; though indeed it may be alledged, that, in this last instance, the pulsations are either owing to the irritation communicated to the heart by the ligature made on these vessels, or to some blood still remaining in its ventricles. Perhaps, when a *stimulus* is very slight, it may cause only one single contraction of a muscle; but when it is greater, it will produce repeated convulsions, and always the more, the stronger it is. The action therefore of the returning blood upon the auricles and ventricles of the heart in living animals, may be supposed not only to excite them once into contraction, but likewise, without the accession of new blood, or any other

* Sect. I. No 11.

other *stimulus*, to cause some subsequent vibrations, always indeed decreasing in force and frequency; but as in the intervals of these vibrations, the heart is again filled with blood, its alternate contractions, being always solicited by a new cause, do not become weaker or slower, but continue the same, while the quantity and quality of the blood are unvaried.

It can be no just objection, therefore, to our account of the heart's motion, that in many animals newly killed, this muscle, by separating it from the body, or otherwise stimulating it, is excited into alternate contractions; which continue to be repeated for a considerable time, though the *stimulus* be not renewed; since the motions of muscles arising from this cause, do not cease immediately upon its removal, but decrease in strength and quickness, by slow degrees, before they quite disappear*: nor ought we to be surpris'd that the violent irritation, occasioned by pricking and tearing the fibres of the heart, or from cutting its large vessels, makes

* Vid. Sect. i. No 11. and Sect. xiv. where the motion of the heart after death, or its separation from the body, is particularly inquired into.

makes it repeat its vibrations more frequently, and continue them for a much longer time, than the gentle *stimulus* of the returning blood.

AT what time the motion of the heart begins in nascent animals, and what is the cause which first sets it a-going, are questions not usually inquired into, nor indeed easily answered; although the second seems to admit of a much easier solution than the first.

IF all the parts and organs pre-exist in miniature in the animalcle *in semine*, it will scarce be disputed, that while it swims in this liquor, the fluids are propelled through its vessels by the action of its heart, and circulate in the same manner as in the *fœtus in utero*. If the heart does not pre-exist in the animalcle, but is formed after conception, then the beginning of its motion must be later. But, be this as it will, we know that in impregnated eggs, the animalcle lies in a death-like state, resembling that of many insects, and some larger animals in winter; and that its heart remains at rest, till by the heat of incubation it is roused into action. After the motions of the chick's heart be-
come

come visible, they may be rendered more lively or languid by a greater or less degree of warmth; nay may be made entirely to cease by cold, and be as quickly renewed again by heat.*. Hence it follows, that though it be not certain when the heart begins first to move in nascent animals, yet the cause which sets it first a-going, and recommences its motions after being stopt, is heat, which, by rarifying and agitating, with an intestine motion, the particles of the fluids, enables them, by their *stimulus*, to excite the fibres of the heart into contraction; at the same time, that it increases the sensibility of the nerves, which are benumbed by too great a degree of cold.

S E C T. V.

Of the motions of the alimentary canal, and bladder of urine.

HAVING thus accounted for the alternate contraction and relaxation of the

* *Harvey de generation. animal. exercitat. 17.*

the heart ; we come next to inquire into the cause of the other involuntary motions ; and shall begin with those of the alimentary canal.

IN deglutition, the contraction of the muscles which pull up the *larynx* and *os hyoides*, and so push the food into the dilated *pharynx*, is generally spontaneous, and owing to the irritation of the sensible membrane of the *fauces*, by the food passing that way. In like manner, no sooner is the aliment received into the *pharynx*, than this muscular tube contracts, and, embracing it closely, pushes it on to the *œsophagus*, whose nerves being irritated, and its fibres stretched by the food in its descent, each small portion of it contracts itself, and so transmits the aliment to the next, till at last it is pushed into the stomach.

THE aliments which are generally composed of parts fit to act as a gentle *stimulus* on the sensible parts of animals, are no sooner received into the stomach, than, by its heat and motion, as well as the action of the humours flowing into it, they begin to swell, and continue, during the whole time of
their

their dissolution, to emit bubbles of elastic air: At the same time, the cool air swallowed, every now and then, with the *saliva*, is quickly rarified by the heat of the stomach.

HERE then, we see, in the aliments, air and humours, causes which may gently stimulate the nerves of the stomach, and stretch its fibres so as to excite them into contraction: and this exactly agrees with *Wepferus's* observations, which shew, that the contraction of the stomach never happens but in consequence of its preceding intumescence. *Motum ventriculi*, says this author, *oculis observare licet in vivarum bestiarum anatome, & non semel vidi illum constringi lentè versus stomachum, subsequente vomitu, aut versus pylorum contentis in duodenum explosis; nonnunquam gracilior & brevior reddebatur; mox iterum intumuit, subsequente rursus nova coarctatione, quæ vel versus pylorum vel stomachum progrediebatur**. And, in another place, *Quando vero circa medium se contraxerat (scil. ventriculus) motus lentè versus pylorum procedebat, illeque erigebatur liquorque subpallidus, nunc spumeus nunc viscidus, quandoque sensim aliquando cum impetu protrudebatur:*

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constricto

* *Histor. cicut. aquat.* p. 87.

*constricto pyloro rursus intumuit totus ventriculus, moxque rursus circa medium se constrinxerat, novusque liquor per pylorum ejiciebatur**.

Thus we find the dilatation of the stomach always succeeded by its contraction, which expelling, by the *pylorus*, the distending cause, *i. e.* part of the air and aliments, the fibres of this organ are immediately relaxed, so as easily to give way to the distending force of the rarified air arising from the aliments, and thus to suffer a new dilatation; which, as before, is soon followed by a new contraction. Hence there appears a remarkable analogy between the causes of the alternate motions of the stomach and heart, even in those animals whose make as to these parts agrees with that of the human kind; but which is still stronger in granivorous birds, whose stomach more nearly resembles the heart in its structure, and in the force of its motions †.

IF

* *Hist. cicut. aquat.* p. 177.

† The small rough stones which granivorous birds swallow, are not only useful to break and grind their food, but also to excite their less sensible stomachs into proper contractions; for these, on account of the hard skin which lines them, would be little affected by the dissolving aliments and rarified air, without the attrition of those stones.

IF it be asked, why the stomach is not brought into a new contraction by the stimulating quality of its contents, before a new intumescence of it has happened ; it is sufficient to answer, that, in order to excite a new contraction of the stomach, or hinder its yielding to the dilating force of the rarified air, the gentle *stimulus* of the aliment may require the additional irritation which the stretching of its fibres produces. Besides, as the convulsive contractions of the diaphragm which happen in consequence of an irritation of the left orifice of the stomach, do not follow one another very quickly, although the stimulating cause continues to operate, but after longer or shorter intervals, according as the irritation is weaker or stronger ; so, in the same manner, after one contraction of the stomach is over, some time may be required for the stimulating cause to act, before a new contraction is produced.

THAT the ordinary vermicular motion of the stomach is chiefly owing to the stimulating quality of its contents, is confirmed by a variety of facts : thus, when any thing is received into the stomach, which strongly

ly irritates or disagreeably affects its nerves, it is thrown into convulsive contractions, which are renewed, after short intervals, till the offending cause is either quite expelled, or greatly weakened. On the other hand, *opium*, which renders our fibres and nerves less sensible of any irritation, has of all things the greatest power to quiet convulsive and irregular motions of the stomach. At the same time, the *nausea* and inclination to vomit, which is sometimes brought on by wind collected in the stomach, or by suddenly drinking too great a quantity of the mildest liquids, shews that the simple intumescence or distension of the stomach, contributes to its contraction independent of any particular *stimulus* affecting its nervous *papillæ*.

THE vermicular motion of the intestines, is quite a-kin to that of the stomach, and produced by the same causes. Small quantities of rarified air and digested aliment are pushed from one portion of the intestinal tube into the next, and from this again into the succeeding one, and so on ; *i. e.* the part dilated by the air and aliments acquires such a power of contraction, as to
overcome

overcome the elasticity or contractile power of the contracted part next it. Whence should this happen? It cannot be owing to the more copious influx of arterial blood into the vessels of the distended segment, as Dr. *Stuart* would persuade us*; since it has been shewn that this fluid does not immediately conduce to the contraction of a muscle†. —There is no reason to imagine, that, on account of any alternate compression of their nerves, the animal spirits are transmitted to the intestines in successive streams: nor would this, if supposed, answer the *phenomena*; since the whole intestinal canal is not, like the heart, alternately contracted and relaxed, but, as to time, is altogether irregular in the motions of its several parts. It remains therefore that the stretching of the fibres of the inflated part of the intestine, together with the *stimulus* of the bile, air, and digested aliments which it contains, is the cause of its subsequent contraction. And surely, if warm air impelled through the *vena cava*, or thoracic duct, into

* Dissert. de motu muscul. cap. 12.

† Sect. i. N° 2. above.

into the heart of an animal newly killed, excites it into contraction, it may reasonably be supposed to have an equal effect on the stomach and intestines, between whose motions and those of the heart there is a strong analogy.

WE have already seen from *Wepferus*, that, by every contraction of the stomach, some part of the more liquid aliment and rarified air is pushed through the *pylorus* into the *duodenum*, which, not finding a free passage through this intestine, on account of its valves and the natural contractility of its coats, will dilate that part of it next the stomach, and consequently excite it into contraction, by which its contents will be transmitted to the next portion of this gut, and so on through the whole tract of the *jejunum* and *ileum*, where the valves being larger, will, by stopping the progress of the chyle and rarified air, occasion more remarkable dilatations, and consequently stronger succeeding contractions.

It will further appear, that the peristaltic motion of the intestines, is owing to the digested aliment, bile and rarified air, acting upon

upon them as a *stimulus*, if we consider that purgatives, which act chiefly by irritating the inside of the guts, greatly increase this motion: — That in animals opened alive, the intestines are excited into stronger contractions, by pricking them with a sharp instrument, or applying any acrid liquor to them: — That such things as render our nerves and fibres less sensible of any irritation, lessen or destroy the peristaltic motion of the bowels; thus Dr. *Kaan* not only found the vermicular motion of the intestines extremely weakened and slow, in a dog to whom he had given six grains of *opium*, but that pricking their external surface with the point of a needle, did not sensibly increase it* — and, lastly, that when the bile from any cause becomes inert, or is hindered from flowing into the bowels, costiveness generally follows. Nay, that the *stimulus* of the bile is, in a particular manner, necessary to the right performance of the peristaltic motion, and that without it the intestines would not be able, sufficiently, to resist the distending power of the rarified

* Impet. faciens, dictum *Hippocrat.* No 435.

rarified air, seems highly probable from the remarkable inflation of the bowels in such as die of an inveterate jaundice; and from the history given by Dr. *Stuart*, of a man who died of a wound in the gall-bladder, who was not only incurably costive, but whose intestines were so much distended with air, that before opening him a tympany was suspected*.

WHILE the chyle is taken up, as it passes along, by the lacteal and absorbent veins of the small intestines, the grosser and less nutritious parts of our humours and aliments are transmitted from the *ileum* by the valve of the *colon* into the great guts, where they remain for some time without giving any disturbance; till, by the pressure of the diaphragm and abdominal muscles in respiration, together with the gentle contractions of the intestines themselves, they are pushed into the *rectum*, where, partly by their acrimony, but chiefly by their weight and bulk overstretching its fibres, they excite this gut into strong contractions, and bring on an insuperable desire of emptying it. When
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* Philosoph. Trans. N^o 414.

any acrid matter lodged in the *plicæ* of the *rectum*, irritates its nervous *papillæ*, as in a *tenesmus*, its muscular coat is excited into frequent and strong contractions, and there is almost a perpetual desire of going to stool. This is best cured by oily and mucilaginous clysters, with *opium*; which at the same time that they sheathe the acrimony, blunt also the sense of pain.

THE bladder of urine is a hollow muscle, which being destitute of any proper antagonist, would always, if not hindered by some foreign cause, reduce itself to its smallest capacity, by means of that natural contraction which is owing to the force of the circulating fluids, the elasticity of its fibres, and the constant but gentle operation of the nervous influence upon them*. This contractile power of the bladder, whereby it reduces itself to its smallest size, is overcome by the urine gradually dropping into its cavity from the ureters; which at length, by overstretching the coats of the bladder, excites its muscular fibres into strong contractions; but these being of

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themselves

* Sect. i. N° 4.

themselves unable to overcome the *sphincter*, the diaphragm, abdominal muscles, and *levator ani*, are called in to their aid: however, after the *sphincter* is opened, the contractile power of the bladder alone is sufficient to expel the whole urine.

THIS fluid, though sensibly acrid, does not, when accumulated in the bladder of a healthy person, give uneasiness so much by the irritation of the nerves of that organ, as by overstretching its fibres: but when the *mucus*, destined to defend these nerves from the acrimony of the urine is abraded, or when the inner coat of the bladder is inflamed or excoriated, no sooner does the urine begin to be collected, than, by fretting this tender and extremely sensible part, it occasions convulsive contractions of the muscular coat of the bladder, and also of the diaphragm and abdominal muscles; hence in such cases the patient is afflicted with a violent and almost constant desire of passing his urine, while in the mean time there are only a few drops to be expelled.

MARES and cows, after evacuating their urine, are observed, for some time, alternately

ly to contract and relax their *urethra* and *sphincter vesicæ*; at first very briskly, afterwards more weakly and with longer intervals between each contraction. These motions are solely owing to the irritation of the parts by the urine; and it is a proof of this, that as the uneasy sensation begins to abate, so does the force and quickness of these motions.

S E C T. VI.

Of the motions of the blood-vessels, and several others of the spontaneous kind.

THE most remarkable of the spontaneous motions which remain to be accounted for, are the alternate *systole* and *diastole* of the arteries; the less perceptible motion of the veins; the oscillatory contractions of the smaller vessels; the erection of the *penis*; the convulsive motions of the *musculi acceleratores urinæ* in coition; the motions of the fallopian tubes, whereby they embrace the *ovaria*, and convey the

ovum to the womb ; the alternate action of the muscles of respiration ; their convulsive motions in coughing and sneezing ; and the contraction of the pupil and muscles of the internal ear, in order to adapt these organs exactly to the degree of light and sound applied to them.

1. THE *diastole* of the arteries is, like the dilatation of the heart, owing to the blood pushed into their cavity, with a considerable force, and their *systole* or succeeding contraction is effected chiefly by their elasticity, and partly by the proper contraction of their muscular coat, excited by the blood gently stimulating their internal surface, and at the same time stretching their fibres. That the *systole* of the arteries is not wholly owing to the elasticity, but partly also to the muscular contraction of their fibres, is generally acknowledged by Physiologists ; and that the blood alternately pushed into them and acting as a *stimulus*, excites this muscular contraction, the analogy of the heart, and other spontaneous motions, already explained, seems fully to evince.

2. BESIDE

2. BESIDE the alternate *diastole* and *systole* of the larger arteries, which, in a great measure, depend upon the projectile force of the heart, and the elasticity of their coats, there is a vibrating or oscillatory motion in the inferior orders of vessels, to which the direct force of the heart does scarcely reach, and where elasticity is no ways concerned. And as the food is conducted from the mouth through the whole course of the alimentary canal, by its exciting the muscular coat of this tube into contractions, as it passes along; so the motion of the fluids through the inferior orders of vessels and secretory tubes of the glands, to many of which the impulsive force of the heart seems not to extend, is chiefly carried on by the vibrating contractions of these vessels, excited by the gentle *stimulus* of the circulating fluids*.

3. As the smaller vessels, though destitute of any alternate pulsation depending upon the

* See this point more fully illustrated in my *Physiological Essays*, edit. 2. Essay 1. on the motion of the fluids in the very small vessels of animals.

the contraction of the heart, are nevertheless agitated with a kind of oscillatory motion; so it is highly reasonable to think, that the veins are not inactive canals, but so affected by the *stimulus* of the circulating blood, as to have their muscular coat excited into alternate, but weak contractions, by means of which the return of this fluid to the heart is partly promoted. As a proof of this, the *vena cava* may be plainly seen to contract alternately in dying animals whose *thorax* is laid open*; though it is probable that the motions of this vein near the heart, are more remarkable than elsewhere, on account of some kind of alternate depletion which it suffers, and of its coats being somewhat more muscular here, than elsewhere. And does not the *vena cava* continue to palpitate longer than the heart in dying animals, because, after the circulation through this organ has ceased, the blood is still transmitted in small quantity from the arteries into the nascent veins, and consequently into the *cava*; which being therefore longer supplied with the cause
exciting

* Sect. xiv. No 16. below.

exciting its motions, must continue them longer?

HENCE we see that the fluids are in some sense the cause of their own motion ; since, without their stretching power and stimulating quality, the heart and arteries, however well fitted for muscular contraction, would remain altogether unactive and at rest : and that as the contractile power of the solids is altogether necessary to carry on the vital functions, so likewise is the action of the fluids upon the solids, in order to excite their muscular power into action. Hence also we may easily understand how it is that heat has so great an influence in promoting the circulation of the fluids, that insects and many other animals, after they are to all appearance dead, may be quickly brought to life by it. Heat not only renders the heart and vascular system more sensible, but, by raising an intestine motion and brisk vibrations in the particles of the fluids, must necessarily communicate some degree of irritation to the solids ; and thus bring them into alternate contractions.

4. THE erection of the *penis* has been generally ascribed to the contraction of the muscles called *erectores*; yet as their situation is such, that the veins of the *penis* can scarcely be affected by their action, and as an erection of this member cannot be procured at pleasure, by strongly pressing it against the *os pubis*, several later authors seem justly to have rejected this opinion, but, as far as I know, without substituting any thing satisfactory in its place.

BUT as the taste, nay even the sight or remembrance of grateful food, makes the *saliva* flow, in greater quantity than usual, into the mouth of a hungry person, by increasing the oscillatory motions of the salivary vessels [N^o 2.]; so, why may not the *stimulus* of the seed in the *vesiculæ seminales*, or the sight, nay even the recalled idea of lascivious objects, occasion a more than ordinary flow of blood through the small arteries of the *penis*, by greatly increasing their vibrating contractions? If this really happens, the small capillary red arteries will, by the increased force of the fluids, be enlarged, and the serous ones, at least many
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of them, will be rendered capable to admit red blood: those arteries which end in veins, will transmit their fluids to them as usual, only with greater impetuosity, while such as terminate with open orifices in the cells of the *penis*, will, through their dilated mouths, pour forth not only a serous or lymphatic fluid, as usual, but also red blood itself; which not being fast enough carried off by the absorbent veins, whose orifices are not enlarged proportionally with those of the arteries, must fill and distend these cavities, and consequently produce an erection of the *penis*. As soon as the causes exciting an uncommon oscillatory motion in the small vessels of the yard ceases, it begins to subside, because the fluids are now poured in much less quantity into its cells.

THIS account of the erection of the *penis* seems to be much more agreeable to the laws of the animal œconomy, than that proposed by *Duvernoi**, and embraced by *M. de Haller*†, who supposes that the small

P. veins

* Aët. Petropolitan. tom. 2. p. 379. 383, 384.

† Prim. lin. physiolog. No. 800.

veins of the *penis* may be so straitened, by I do not know what contraction of the nervous filaments surrounding them, as in a great measure to prevent the return of their blood*. *Vieußens* who considered the nerves, which in some places appear to surround the blood-vessels, as so many small cords capable of constricting them more at one time than another, and consequently of producing remarkable changes in the circulation, deduces the paleness of the face in some passions, and its redness in others, from the nerves straitening the carotid arteries in the former, and the jugular veins in the latter case†. However, none of the authors now mentioned, have condescended to shew us how the nerves can be so drawn as, like a ligature, to straiten the vessels which they encompass. Nor indeed can this be easily conceived. There is no example to be found

* Supposing the nerves could, like cords, straiten the veins of the *penis*, yet an erection of this member would not be the consequence; for tho' a ligature made on the *penis* near the *os pubis* makes it well, yet this swelling is quite different from a true erection. See *Albinus's annotationes academicæ*, lib. i. cap. xviii.

† Neurograph. lib. iii. cap. iv. p. 182.

found of any motion or action in the animal body being performed by the contraction of the nerves, whose office is not to be drawn or rendered more tense at one time than another, but to supply the muscular fibres every where through the body, with that influence or power which seems to be immediately necessary to their contraction : but, by the increased oscillatory motion of the small vessels, which we have assigned as the cause of the erection of the *penis*, we daily observe a variety of sudden and surprising changes produced in the circulation. To this is to be ascribed the profuse secretion of pale limpid urine, to which hysterical people are so liable ; as also the great discharge of tears from the lachrymal vessels, in people affected with great joy or grief. And the blushing, or redness and glowing warmth of the face, which attends a sense of shame, is not owing to the constriction of the temporal veins by means of the nervous filaments from the *portio dura*, which surround them *, but to an increased oscillatory

* *Haller* not. in *Boerhaave*. institut. med. parag. 573. & prim. lin. physiolog. N^o. 552.

oscillatory motion of the small vessels of the face, which in most people, more or less, accompanies a consciousness of shame: for as the rosy colour, and sudden warmth, which are the necessary consequences of the increased motion of the blood in the smaller vessels, ill agree with the stagnation of this fluid, as arising from any compression of the temporal veins; so their being often diffused over the neck and breast, clearly shews that they cannot proceed from this cause. Why this affection of the mind should produce such a change in the circulation of the blood in those parts rather than any other, we do not pretend to say. Sufficient it is, that from experience we know that the body and its several parts are variously affected by the different passions of the mind.

AFTER what has been said, it will be easy to account for the erection of the nipple of a woman's breast, and the swelling of a turkey-cock's comb and rattles, which are much a-kin to the erection of the *penis*, and which, as M. de *Haller* has justly observed, are certainly not owing to the contraction of

of any muscle hindering the return of the blood by their veins*. For why may not the passion of anger or pride occasion an inflation of the above mentioned animal's comb and rattles, as well as the sense of shame does a flushing of the face? and may not titillation increase the motion of the fluids in the small vessels of the nipple, in the same manner as in the *penis*?

THE unusual sensation of heat in the face, which attends blushing, and is so quickly raised, may enable us to account for the many sudden complaints of heat and cold, and other symptoms of a like nature common to hysterical people; for if an affection of the mind, can raise an uncommon heat in the face, by increasing the action of the nervous influence upon its vessels, whence they are affected with an uncommon vibratory motion; why may not the same thing happen in other parts of the body, in consequence of an irritation of their small vessels, or of some commotion of the nervous system? and is it not probable, that the sudden sensations of cold, which people subject

to nervous complaints often feel in various parts of their bodies, are owing to the stagnation or slower motion of the fluids in the smaller vessels of these parts, occasioned by the diminution or suspension of their oscillatory motion?

BUT to return from this digression; whether the erection of the *penis* is effected in the manner above explained, or by the contraction of certain muscles compressing its veins; it is nevertheless, like the other spontaneous actions, owing to an irritation, viz. the *stimulus* communicated to the nervous *papillæ* of the *vesiculæ seminales* and testicles by the seed; since, in proportion to the abundance or defect of this, erections are *ceteris paribus* more or less frequent, stronger or weaker. 'Tis true, that lascivious thoughts, titillation, and other causes, often produce erections of the *penis*; but even their power of doing this, is in a great measure owing to the presence of the seed.

AN erection of the *penis* frequently happens from the bladder being full of urine, at least is increased by this; which is noways
 strange,

strange, since the urine, by stretching and stimulating the coats of that organ, may be easily supposed to affect the nerves and vessels of the *penis*, with which the bladder is so nearly connected.

5. IN time of coition, as soon as the seed is squeezed into the beginning or bulbous part of the *urethra*, the *musculi acceleratores urinæ* which surround this part, are brought into convulsive contractions, which continue to be repeated till the seed is entirely expelled; and that these convulsive contractions are owing to the *semen* acting as a *stimulus* upon this part of the *urethra*, cannot with any colour of reason be denied; since their number and force are always greater or less, as this liquor is more or less in quantity, or more or less concocted.

6. By the titillation of the *rugæ* of the *vagina* in time of coition, not only is the *uterus* affected, but the *tubæ fallopianæ* becoming rigid, suffer a kind of erection; at which time their fimbriated extremities are turned towards the *ovaria*: nor do they
change

change this situation till the *ovum* has been received into their cavity, through which it is pressed forward to the *uterus*, by the contraction of the muscular coat of those tubes; which, from the analogy of the other involuntary motions already explained, we may easily imagine, is excited by the *ovum* as it passes along their internal surface; so that every small portion of it, will, by its contraction, transmit the *ovum* to the succeeding one, till at last it drops into the cavity of the womb; in the same manner as the food, in a horizontal posture, is conveyed through the *œsophagus* into the stomach.

THAT the convulsive motions of the muscles of respiration in coughing and sneezing, and of the diaphragm in the hiccup, are owing to an irritation of the sensible membrane of the nose, windpipe, and inferior part of the gullet, is too evident to need any particular proof; and this the rather, as these motions will be occasionally illustrated in the sequel of this Essay. Nor is it less true, that the motions of the pupil and muscles of the internal ear, are owing

to light and sound acting as *stimuli* on these organs: but as these motions, whereby the eye and ear are accommodated to different degrees of light and sound, are more intricate and less generally understood, I shall treat of them particularly in the following Section. And as the alternate motion of the organs of respiration differs from the other spontaneous motions already explained, in being so far under the power of the will, that we can accelerate, retard, or entirely (at least for a considerable time) put a stop to it; and is a subject upon which a great deal may be said, I shall also treat of it afterwards in a particular Section by itself; where its cause will be shewn to be entirely analogous to that of the other spontaneous motions.

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S E C T.

S E C T. VII.

Of the motions of the pupil and muscles of the internal ear.

AS the degrees of light to which the eye is exposed, and the splendor of the objects presented to it are various, had the pupil been of a determinate size, incapable of enlargement or diminution, that organ would have been adapted only to contemplate objects in one particular degree of light ; every thing remarkably brighter than this, would have dazzled it, while a fainter light would not have affected it sufficiently. Further, as the rays of light coming from very near objects, are much more divergent than those from remote ones, had the pupil been incapable of variation as to its extent, the eye would have been ill fitted for seeing distinctly at different distances ; since such objects alone are seen distinctly, whose images are accurately painted upon the middle and most sensible parts of the *retina*.

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To prevent these inconveniencies, and that the eye might be capable of receiving properly the impressions of objects in a great variety of lights and distances, that membrane called by Anatomists the *uvea* or *iris*, which encompasses the pupil, is furnished with a double set of muscular fibres, by whose contraction or relaxation, the diameter of this passage can be greatly augmented or diminished. One plane of these fibres is circular, and immediately furrounds the circumference of the pupil: it may very properly be called the *sphincter pupillæ*, since, by its contraction, the pupil is lessened. The other is composed of a number of radiated fibres, which take their rise from the great circumference of the *uvea*, where it is attached to the *circulus albus*, or union of the *cornea* and *sclerotica*, and are inserted into the orbicular muscle above mentioned, all round the circle of the pupil, as the spokes of a wheel are into its nave. This plane of muscular fibres acts as antagonist to the orbicular one, and may be called the *laxator* or *dilatator pupillæ*.

THE circular plane of fibres is so thin and delicate, that several authors of note have doubted of its existence ; but in admitting it, we are not only justified by the authority of the best Anatomists*, but by reason and analogy ; since the equable and regular contraction of the pupil cannot well be conceived, without supposing some such mechanism ; and since we find the other passages in the body which are endued with a power of contracting themselves, furnished with *sphincter* muscles.

FURTHER, although the circular and longitudinal fibres of the *uvea* are so delicate, that their muscular structure cannot be clearly demonstrated by Anatomists, yet they may be sufficient for the performance of the various motions of the pupil ; for we daily meet with insects whose agility shew them to be furnished with muscles, although these instruments of motion in them, are too minute to be discovered by the most subtile dissector.

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* *Winflow* anatom. sect. 10. N^o 220. *Ruyfch.* thesaur. anatom. 2. tab. 1. fig. 5. lit. c.

THE figure of the pupil, as well as its degrees of contraction and dilatation, are different in different animals. In man the pupil is at all times perfectly round; in horses, cows, &c. it is oblong and transverse; and in cats in the day-time, it forms a narrow chink perpendicular to the horizon, but in the dark acquires nearly a circular figure, and becomes almost as large as the *cornea*. If in cats the pupil had been perfectly circular as in man, it could not well have admitted of so great degrees of dilatation and contraction, which yet are necessary to an animal which must seek its prey in the night-season; at least, when most contracted, its edges must have been remarkably furled, and their thickness greatly increased, by being folded together in so small a space. Moreover, it is observable, that all those animals which have the pupil of an oblong or oval shape, are capable of seeing in a much fainter light than man.

Galen, who did not allow any motion to the pupil, except when one of the eyes is shut, ascribed the dilatation of the pupil of
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the open eye, to its having the spirits which used to be bestowed on both eyes, now determined into it alone. *Achillinus*, who flourished in the beginning of the sixteenth century, makes particular mention of the motion of the pupil from different degrees of light*; which however was so little attended to, that its first discovery has been generally ascribed to Father *Paul* of *Venice*, who lived about a hundred years after him†. However, neither Father *Paul*, nor *Aquapendente* his cotemporary, seem to have known any thing of the manner in which these motions are performed. Nor ought it to appear strange, if, before the muscular structure of the *uvea* was known, Physiologists were quite in the dark with regard to the pupil's motions, or if their accounts of this matter be altogether as wide of the truth, as different from each other.

THE natural state of the pupil is that of dilatation; for since the longitudinal fibres
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* *Morgagni. adversar. anatom. i. p. 34.*

† *Fabricius ab Aquapendente de oculo, part. 3. cap. 6. Plemp. Ophthalmograph. lib. i. cap. ix. et Douglas bibliograph. anatom. p. 228.*

of the *iris* are much more conspicuous and stronger than the circular plane, they must, by their natural contraction *, keep the pupil always dilated, unless the latter are excited into action by some particular cause.

WHAT this cause is, could be no difficult matter to discover : for, as in a *syncope*, apoplexy, or at the moment of death, when the eye is quite insensible to external objects, the pupil is always greatly dilated ; as in the shade it is remarkably large, and always the more so, the greater the darkness ; while in a bright light it is contracted almost to a point ; it clearly follows, that the coarctation of this passage is owing to the action of light on the eye as a sensible organ, and its dilatation to the superior contractile power of the longitudinal fibres of the *uvea*, when the eye is left to itself, and not affected by any external cause.

THE pupil is contracted more or less in proportion to the quantity of light admitted into the eye, not on account of any immediate action of this subtile fluid on the fibres
of

* Sect. i. No. 3. and 4. above.

of the *iris*, as some have imagined*, but in consequence of its affecting the tender *retina* with an uneasy sensation. Hence whatever intercepts the rays of light so as to prevent their affecting the *retina*, or whatever renders this membrane insensible to their action, occasions a preternatural dilatation of the pupil. Thus, in a cataract, where the crystalline humour being considerably opaque, intercepts a great part of the luminous rays in their way to the *retina*, the pupil is not so much contracted as in a sound eye. In a confirmed *gutta serena*, or perfect insensibility of the *retina*, the orbicular muscle of the pupil loses its power of contraction altogether, insomuch that this passage remains equally wide in the brightest sunshine, as in the obscurest shade. If the action of light on the circular fibres of the *iris* were the cause of their contraction, this ought not to happen; since the nerves of this membrane, as they have no connexion with the optic nerve, ought to remain equally fit for actuating its orbicular muscle, and

* Histoire acad. des sciences 1704, édit. 8vo, p. 18. & Mémoires, p. 360.

and equally sensible of the *stimulus* of light, when the *retina* is thus diseased, as in a sound eye. But if it shall be alledged, that in a *gutta serena*, the nerves of the *uvea* become some how paralytic, and that the immobility of the pupil is owing to this, and not to the insensibility of the diseased *retina*; I answer, that a plain experiment shews the contrary: thus when one eye is quite lost by a confirmed *amaurosis*, if the sound one be covered or kept shut, the pupil of the diseased eye remains in every degree of light immoveable, and of the same size; but if the sound eye is exposed to the sun-beams, the pupil of the other, which shewed no motion before, will be evidently observed to contract. This contraction can only arise from the sympathy between the two pupils; and shews, that when the sound eye is covered, the defect of motion in the morbid one is not owing to the nerves of the *uvea* being any ways paralytic, but merely to the want of a cause increasing their action upon the orbicular muscle of the pupil.

FURTHER, if the contraction of the pupil proceeds from light acting as a *stimulus* on

the fibres of the *iris*, why does it not excite its longitudinal fibres equally into action as its circular ones?

WHEN the head of a living cat is put under water, its pupil, which was much contracted before, is immediately greatly dilated, though exposed to the sun-beams. If the contraction of the *sphincter pupille* arose from the action of light on its fibres, this *phenomenon* would hardly admit of a solution; since it does not appear that the rays of light should act with much less force upon the *iris* of an animal under water, than in the open air: but, on supposition that the contraction of the pupil is owing to the *stimulus* of light affecting the *retina*, it is easily accounted for. The rays of light passing from air into the eye, through the *cornea*, suffer a considerable refraction on account of its greater density; by which means they are made to approach one another so, as by the refractions of the crystalline and vitreous humours, they may be collected in a point on the *retina*. But when the head of an animal is under water, the rays of light suffer little or no refraction in passing through
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the *cornea* and aqueous humour, because their density scarce differs from that of water: hence they will not, as in the former case, be made to approach one another, nor will they have their *focus* in the *retina*, but a great way behind it; this membrane, therefore will be very weakly affected by them, and consequently the pupil must be dilated. In water there is a general and faint light diffused over a great part of the *retina*; in air all this light is collected, and acting on a much smaller space, is greatly more vivid and striking.

MR. Mery indeed has given a different solution of this *phenomenon*; but such a one as will not give a philosophical reader any very exalted *idea* of his knowledge either in physiology or in optics. His account of the matter is this. Under water, the animal is hindered from breathing, but the motion of the spirits, to which he ascribes the contraction of the pupil, depends on the circulation of the blood, and this again on respiration; therefore, notwithstanding the usual action of light on the *iris*, the pupil in an animal under water, must be relax-

ed merely on account of the interruption of respiration *.—It is most certain, that in a *syncope*, when the vital motions cease, the pupil is dilated in air, as well as in water, because the *retina* loses its sensibility ; but a cat plunged into water, does not become immediately insensible, nor does the motion of its heart cease with that of respiration ; and if a man can restrain breathing near a minute, without losing any of his senses, this animal, which bears the air-pump so long, must continue sensible and lively under water for a much longer time : add to this, that the cat's pupil is observed to be greatly dilated immediately after immersion ; whereas, according to Mr. *Mery's* principles, it should become gradually wider as the animal languishes more and more.

SINCE the optic nerves and those of the *uvula* arise from different parts of the brain, and have no communication with each other in their course to the eye, it seems evident, that light affecting the *retina*, cannot excite the *sphincter* of the pupil into contraction,

* *Memoires acad. des sciences* 1704. edit. 8vo. p. 353.

traction, by any immediate mechanical change which it produces, either in the muscle itself, or in the nerves which actuate it; but the uneasy sensation occasioned in the *retina* by the admission of too much light into the eye, may so affect the sentient principle, which is present and ready to act, where-ever the nerves have their origin, as to excite it to contract the orbicular muscle of the *uvea*, in order to lessen the pupil, and exclude the offending cause. While the eye remains in the same degree of light, and directed towards the same object, the pupil remains invariably of an equal size, as the same cause continues uniformly to excite the mind to determine the nervous influence in the same degree into its *sphincter* muscle: but no sooner does the light become fainter, than the sentient principle, being less affected, ceases to contract this muscle, and allows the curtain of the pupil to be opened by the natural action of its longitudinal fibres, by which means more light is admitted into the eye.

WHEN the eye is suddenly removed from a very faint into a bright light, a considerable

able dazzling, with an uneasy sensation, is plainly perceived; and though in smaller changes this is much less perceptible, yet it may be sufficient to excite the mind to contract the pupil so far as may be necessary in such cases to defend the tender *retina*.

IF it be asked, why the orbicular muscle of the *uvea* is rather contracted than its longitudinal fibres, upon the admission of light into the eye; the answer is, that the contraction of the latter, would not tend to remove the uneasy sensation, but to increase it: and such is the original constitution of our frame, that the mind or sentient principle is, in consequence of certain uneasy sensations, instantly determined to produce such motions or changes in the body, as naturally tend to remove or lessen them.

WHEN a candle is placed before the eyes, if one of these organs is covered with one's hand, or an opaque body, the pupil of the other will be observed immediately to become wider. Now, as the muscles of the *uvea* of the one eye have no manner of connexion with those of the other, either by means of nerves or blood-vessels, unless it
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be that the former are derived from different parts of the same brain, and the latter from the *aorta*, this consent in their motions must be altogether inexplicable upon mechanical principles alone : for if the action of light on the eye is the cause of the contraction of the pupil, why should not the pupil of the open eye remain equally contracted when the same degree of light continues to act upon it ; or why should it be affected by the relaxation of the other pupil, with which it has no immediate connexion, while the mechanical cause of its own contraction continues to act with undiminished force ?

BUT if we allow the contraction of the pupil to be owing to a sentient active principle, which, in proportion as it is more or less affected, by the uneasy sensation arising from the action of light on the *retina*, contracts the pupil in a greater or less degree ; then, when one eye is shut, its *retina* being no more exposed to the light, and consequently the sentient principle being no longer excited to contract the orbicular muscle of the *uvea*, its pupil must be widened by the natural contraction

contraction of the stronger longitudinal fibres of that membrane : but as the mind has, from the time of birth, been always accustomed to contract the pupils of both eyes at the same time, the one pupil can no more be relaxed without the other being partly so, than one eye can be directed to the nose, while the other is turned from it : for how much soever the motions of certain muscles are owing to the immediate energy of the mind, yet it is undeniable, that, by constant habit, we soon lose the power of moving them, except in a particular way ; and as this is true of the eyes, whose motions are quite of the voluntary kind, and may be performed or restrained at pleasure, it cannot with any colour of reason be denied to take place in such muscles, whose action is from the beginning independent on the will.

As in the above mentioned experiment the pupil of the open eye is considerably relaxed, on account of the consent of its motions with the pupil of the other, so it is not to be doubted, but that the pupil of the
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covered eye is less enlarged than it would be, if no light was admitted into the open one: thus in a *gutta serena*, the blind eye has its pupil sensibly contracted, when the sound one is exposed to a bright light, *i. e.* the diseased pupil follows in some degree the motions of the sound one, and, by the action of light upon it, is hindered from being so much relaxed as it would otherwise be. It is however probable, if a perfect *amaurosis* was to continue long in one eye without affecting the other, that this consent between the pupils, as to their motions, would gradually become less remarkable, till at last the pupil of the diseased eye would cease to be lessened almost in any degree by the action of light on the sound one.

WHEN a candle is so placed as to shine full upon one eye, without any of its rays having access to the other, the pupil exposed to the light is observed to be somewhat less than the other; though neither of them is so much contracted, as if both eyes were equally affected by the light. Hence it fol-

lows, that notwithstanding there is a remarkable uniformity between the pupils of both eyes as to their motions, yet they do not exactly keep pace, but the pupil immediately exposed to the greatest light is most contracted. And this serves further to shew, that when one eye is covered, the pupil of the open one becomes wider, from the consent between its motions and those of the darkened one; and not, as some may perhaps imagine, because the mind receiving only the impresson of light acting upon one eye, and therefore being less affected than when both eyes are open, makes a less effort to exclude the light, by contracting the pupil. The reader will, however, easily perceive, that in both ways of explaining the above *phænomenon*, the necessity of deducing these motions of the pupil from the mind, is equally acknowledged.

IF it shall be alledged, that the contraction of the pupil is not owing to the action of light on the *retina*, but on the choroid coat, and that the *uvea* being a continuation of this membrane, and having its nerves
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from the same source, may easily be supposed to have a remarkable sympathy with it. Without entering into the dispute, whether it is the *retina* or choroid that receives the impression of objects, and feels the *stimulus* of light ; I answer, that as the agreement just now observed between the two pupils as to their motions, cannot possibly arise from any mechanical consent between them, but must be owing to some common PRINCIPLE in the brain ; so it is highly reasonable to imagine, that the contraction of the orbicular muscle of the *uvea*, in consequence of light being admitted into the eye, proceeds from the same cause, and not from any connexion between the choroid and *uvea* : for supposing it did, why should its circular fibres rather than its longitudinal ones be contracted ; since, as the latter are nearer to, and more immediately derived from the choroid than the former, one would be apt to think their sympathy with it should be the more remarkable.

HAVING, as we hope, given a clear and consistent account of the pupil's motions, so far as they are owing to different degrees
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of light applied to the eye; it may not perhaps be improper, briefly to point out a few mistakes of some authors of considerable character, with respect to this matter.

MR. *Mery*, not being able to observe any circular fibres in the *iris*, whose contraction might account for the constriction of the pupil, endeavours to prove that this is owing to the inflation and elongation of its longitudinal fibres by the animal spirits being more copiously derived into them; and that the dilatation of the pupil is owing solely to the spring or elasticity of these fibres, whereby they become shorter when left to themselves*. But there is no instance in the human body, of any muscle becoming longer by a more copious derivation of the nervous influence into it; the constant effect of this is, to swell, harden, and shorten the muscle at the same time. Nor indeed would it be easy to conceive (allowing a singular structure in the longitudinal fibres of the *iris*) how they could be so lengthened by the influx of animal spirits, as to reduce the pupil almost to a point, without,

* *Memoires acad. des sciences* 1704, edit. 8vo. p. 352.

without, at the same time, being so inflated as to make a very remarkable difference in the thickness of this membrane.

THE ingenious *M. de la Hire* imagines, that as a bright light, by disagreeably affecting the bottom of the eye, excites us to contract the pupil; so, in the dark, we do our utmost to dilate it, that we may see more distinctly*; that is, its dilatation is owing to an effort of the will, occasioning a stronger action, than usual, of the influence of the nerves on the longitudinal fibres of the *iris*. To prove this, he says, that cats in a luminous place, when they do not seem to be taking notice of any thing around them, have their pupils almost quite shut, but that, as soon as any extraordinary object presents itself, so as to draw their attention, they immediately, and at once, open their pupils considerably†. If this be true, as I dare say it is, then cats must be allowed to have a power of dilating, and probably also of contracting their pupil at pleasure, when the quantity of light applied

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* *Memoires acad. des sciences* 1709. edit. 8vo. p. 121.

† *Ibid.* p. 121, 122.

to their eyes remains the same ; which however is not the case with men, in whom the wideness of the pupil in a *syncope*, apoplexy and confirmed *gutta serena*, shews, that, in order to dilate the pupil to its largest size, no effort of the mind is necessary, but only the superior contractile power of the longitudinal fibres of the *uvea*, when its circular muscle is not excited into action by the *stimulus* of light on the *retina*. Nor have I ever been able to observe that the pupil is narrower in a light room, when one does not attend to any thing around him, and becomes wider as soon as he looks at any object within a proper distance of the eye, so as to see it distinctly.

THE same author, in consequence I suppose of his above mentioned notion of the voluntary dilatation of the pupil, also alleges, that, in a bright light, when we look attentively at an object in order to see its small parts, the pupil is not so much contracted as it would be by the action of this degree of light alone, did we make no such effort to see any thing distinctly *. This, however,

* *Memoires acad. des sciences* 1709, edit. 8vo. p. 121, 122.

however, is so far from being true, that it will appear, from experiments to be mentioned below, that in the strongest light the pupil is less contracted when we make no effort to see any thing distinctly, than when we look with great attention to a near object, so as to observe its minute parts.

THE learned M. *de Haller*, equally doubtful of the existence of the circular, and of the action of the longitudinal fibres of the *uvea*, deduces the contraction of the pupil from the *stimulus* of light affecting the *iris*, and occasioning a greater flux of humours into its fine pellucid vessels, by which means they are extended in length, the *iris* is rendered broader, and consequently the pupil narrower. The dilatation of the pupil, he ascribes to the aqueous humour pressing its edges outward, when the powers contracting it, and consequently resisting the pressure of this fluid, are weakened*. But, if the contraction of the pupil was owing to the elongation of the vessels of the *iris*, from the humours moving with greater force through them, then, in animals newly dead,

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* *Primæ linæ Physiolog. sect. 506. et 515.*

warm water injected into the carotid artery, should make the pupil contract sensibly. Further, the *iris* should become thicker and its vessels should swell; since the greater force of the fluids moving in them must increase their transverse diameter, as well as their length: thus when the *penis* is erected by the effusion of blood into its cells, it becomes thicker, as well as longer. Lastly, as this theory supposes the contraction of the pupil to proceed from the action of light as a *stimulus* upon the sensible vessels of the *iris*, it may be looked upon as sufficiently confuted, by what has been offered above, to shew that it is to the action of light on the *retina*, and not on the *iris*, that the contraction of the pupil is owing*.

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* It has been urged as a proof of M. de Haller's opinion concerning the contraction of the pupil, that when the jugular veins were tied in a cat, the pupil became narrower†; but this experiment only shows that the vessels of the *iris* as well as the vessels of the *conjunctiva* and indeed of the whole face, are much distended, when the return of the blood from them to the heart is prevented. This distension of the vessels of the *iris* must have rendered the pupil somewhat narrower;

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† See *Relationes de libris novis* Gotting. 1757.

WITH respect to M. *de Haller's* account of the dilatation of the pupil; it were sufficient to observe, that as the watry humour, like all other fluids, must necessarily press the parts of the *iris* as much inwards toward the pupil, as outwards toward the *cornea*, it is evident it can have no effect in widening the pupil. Unless therefore this learned author will shew, contrary to the first and hitherto universally received principles of hydrostatics, that the parts of the aqueous humour are not in *equilibrio* among themselves, his opinion must necessarily fall to the ground. But further, if the dilatation of the pupil was not owing to the natural contractility of the longitudinal fibres of the *uvea*, but merely to the pressure of the aqueous humour upon its edges, when the power contracting it ceases to act; the pupil should, contrary to experience, continue to grow wider for some time after death, because the vessels and fibres of the

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iris,

but this diminution of the pupil is as different from its contraction occasioned by light, as the swelling of the *penis*, in consequence of a ligature made upon it, is different from a true erection of that member.

iris, becoming then remarkably more flaccid, must be less able to resist the supposed pressure of the aqueous humour: but if the enlargement of the pupil, is owing to the natural contraction of the longitudinal fibres of the *iris*, as has been above explained, then it will evidently appear why the pupil does not become wider, but rather narrower after death, because these fibres which retract its edges, gradually lose their contractile power, and are somewhat lengthened*.

THE accurate *Winflow* is, I believe, the first who observed that the pupil becomes less after death. In some bodies he found it of a moderate size, in others a good deal more contracted, but never much dilated, as we know happens in a *gutta serena*, *syncope*, *apoplexy*, &c. †. The pupil, however, not only thus becomes narrower after death, but also sometimes before it.

THUS in a boy of 5 years of age, who had been for some days comatose, the pupil

* See some farther observations on this subject in my *Physiological Essays* edit. 2. p. 144, &c.

† *Memoires acad. des sciences* 1721. edit. 8vo, p. 416.

pil first became remarkably wide, and was not sensibly affected by a lighted candle brought very near the *cornea*: about 15 hours after this, looking into his eye, I observed, with surprize, the pupil not larger than in a sound eye in a moderate light.

AT this time having endeavoured to rouse him, by holding spirit of *sal ammoniac.* to his nostrils, and making him swallow some cinnamon water with *sp. volat. oleos.*, the pupil was thereby suddenly dilated, and became as wide as it had been the evening before. After half an hour, he fell into a greater degree of *stupor*, and his pupil became remarkably less as above, and remained equally so in all degrees of light; but upon applying spirit of *sal ammon.* to his nose, it was quickly enlarged, so as to occupy two thirds of the *cornea*. This experiment I repeated four times in the space of two days, and always with the same success. During most of this time, this child's pulse was strong and full. When his head was opened after death, there were found immediately below the *corpus callosum*, about two ounces of water.

FROM this remarkable history, it seems manifest, that the dilatation of the pupil soon after the coming on of the *coma*, was owing to the compression of the *thalami nervorum optitorum*, by the water collected in the brain, which rendered the *retina* insensible of the *stimulus* of light. Soon after, the origin of the nerves of the *uvea* beginning to be compressed by the growing collection of lymph, the longitudinal fibres of this membrane lost their power of contraction, and became flaccid, almost as in dead bodies; whence the edges of the pupil were less retracted. The volatile spirits applied to the olfactory nerves, by giving a shock to the whole brain and nervous system, in some degree opened the obstructed nerves of the *uvea*, so as to allow their influence to be derived into its fibres, the necessary consequence of which was the dilatation of the pupil. But as soon as the effect of this *stimulus* was over, the influence of their nerves being again intercepted, the longitudinal fibres of the *uvea* were relaxed, and therefore the pupil was less dilated. As these different states of the pupil were more remarkable

markable in the left than in the right eye, it is probable, that one side of the medullary substance of the brain was somewhat more compressed than the other. Lastly, since, after the pupil was enlarged by the *stimulus* of the volatile spirits, the eye still remained wholly insensible to the action of light, it is reasonable to think, that the pressure upon the origin of the optic nerves was greater, than upon that of the nerves of the *uvea*.

2. THE motions of the pupil are not only necessary to adapt the eye to different degrees of light, but also to the distinct vision of objects at different distances. Thus if a book which one can easily read at the distance of two feet, is gradually brought nearer the eye, till the letters can be no longer distinguished, the pupil will be observed to become narrower in proportion as the book approaches the eye. Again, if one looks first to a candle two or three feet distant, and immediately after to the point of a quill, or any such object, within five or six inches of the eye, and nearly in the same direction

direction with the candle, the pupil will be sensibly contracted : now, as the same quantity of light from the candle, shines upon the eye in these two cases, the greater contraction of the pupil in the latter case, cannot be owing to the light more strongly affecting the *retina*, but to an effort of the mind to see the object more distinctly. This is still further confirmed by the following experiment ; let one with his back to the light, first look to an object of a lively colour at the distance of three or four feet from his eyes, and afterwards to a dark one at the distance of five or six inches, and the pupil will be observed to become sensibly narrower when he looks at the near object, altho' the quantity of light reflected from it is less. Hence the learned Dr. *Jurin* seems to be mistaken when he says, that in a faint light the pupil is so far from contracting in order to distinct vision, that there is rather a necessity of dilating it in order to take in more light* ; for in a faint light the pupil is always observed to be wider, when we look

* Essay on distinct and indistinct vision at the end of *Smith's* Optics, p. 145.

look at an object three or four feet from the eye, than when it is placed so near it, as to be seen indistinctly.

THE necessity of the contraction of the pupil when we look at near objects in order to render vision more distinct, is easily understood; for as in near objects the divergency of the rays is much greater than in distant ones, and as those rays only serve for distinct vision, which do not diverge much from the *axis* of each pencil, the pupil must be contracted, in order that the useless or disturbing ones may be excluded. The contraction therefore of the pupil in viewing near objects, is not solely owing to the spissitude of the rays reflected from them, as *Plempius*, and others after him, have thought*, but chiefly to an effort of the will in order to distinct vision: in like manner, when we look at remote objects, the pupil not only becomes wider, because the rays are thinner, and consequently their light fainter, but also because its *sphincter* muscle, on account of the weakness of the light, is not near
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* *Plemp.* ophthalmogr. lib. 3. cap. 8. and *Haller.* comment. in institut. Boerhaav. sect. 536.

so much contracted in order to distinct vision, as when we view objects which are placed at a less distance from the eye, than the limit of distinct vision.

IN viewing distant objects, the pupil is not widened by any effort of the mind, but its size is *chiefly* determined by the quantity of light applied to the eye, which, as it is, *cæteris paribus*, fainter in distant than in near objects, must occasion a small degree of dilation in the pupil, when we contemplate the former: but in looking at any thing nearer the eye, than that distance at which we see distinctly, and with the greatest ease, the contraction of the pupil is *principally* owing to a voluntary exertion of the mind's power in order to render vision more distinct; and but in a very small degree, to the stronger and more vivid light, which the object, *on account of its vicinity*, reflects upon the eye*.

Maitre

* Altho' the learned Dr *Porterfield* has quoted this paragraph in such a manner (particularly by leaving out these words, *on account of its vicinity*) as to find ground for censure; (a) yet its truth is clearly proved by the following easy experiment. If, while one looks steadfastly at a pin at the distance

(a) See his treatise on the eye, vol. 1. p. 171.

Maitre Jan has, by a wonderful mistake, asserted, that the pupil is lessened when we look at distant objects, and enlarged when we behold near ones; and is at great pains to shew the usefulness of these motions to distinct vision. But his reasoning on this head is extremely weak, and scarce consistent with any tolerable knowledge of optics*.

THE author of the *Essais de physique*, has fallen into an error no less inconsistent with the laws of vision, when he affirms, that the images of objects in the bottom of the eye, are greater or less, as the pupil is more or less dilated; and hence accounts for the sun's appearing much larger when he first gets above the horizon, than at mid-day, when his greater splendor makes the pupil to be more contracted†.

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stance of three feet from the eye, another pin be placed in the same right line in the *axis* of vision, within three or four inches of the eye, the pupil will not be sensibly lessened, although more rays enter the eye from this near pin than from the more distant one; but as soon as the person views the *near* pin, the pupil will be evidently contracted in order that it may be seen more distinctly.

* *Maladies de l'œil*. chap. viii. & xxi.

† L. 'Anatome d'Heister, avec *Essais de physique*, edit. 2. p. 703.

objects ought to appear always largest in the faintest light ; which we do not find confirmed by experience. Further, since the image of any object is formed by the union of the pencils of rays that flow from each point of the object in correspondent points of the *retina*, it is evident, that its magnitude depends on no other circumstances, but the real magnitude of the object, and its real distance from the eye*. The different size of the pupil may, agreeably to what has been observed above, affect the lustre and accuracy of the several points of the image, but cannot alter their distance, because the *axis* of the several pencils, and their angles of inclination, continue the same, whatever is the bulk of the pupil.— Any one may satisfy himself at once, by an easy experiment, that the contraction and dilatation of the pupil cannot alter the bulk of the image of any object formed on the bottom of the eye ; for the picture which
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* It is not affirmed, that the apparent magnitude of objects depend on the circumstances here mentioned alone ; for we are well aware, that experience, the known distance of objects, and other things, have great influence in this matter.

is made by a common *lens* on a sheet of paper, will be found to shrink or swell, when greater or lesser concentric portions of the *lens* are covered.

As we have already seen, that the pupil cannot be so much contracted by the action of light alone on the eye, as when, along with this, there is an effort of the will to see a near object more distinctly ; so the pupil cannot, by any effort, in order to distinct vision, be as much lessened in a faint light as in a bright one. Thus, if one with his back to the windows of a room, brings a small printed book so near his eyes, that he cannot, without straining, distinguish the letters ; upon turning his face quickly to the light, he will be able to read with little difficulty * ; because, by the action of the stronger light on the *retina*, the pupil is immediately lessened, and therefore its power, to prevent the dissipation of the rays, and consequently indistinct vision is increased. Hence neither the single effort of the mind to avoid indistinct vision, nor a vivid light
alone,

* See Dr Jurin's essay on distinct and indistinct vision.

alone, can contract the pupil to its least size, that is, not so much as when both these causes of its contraction are united.

IN infants, but more especially in such as are newly born, the pupil is observed to be wider in proportion to the breadth of the *iris*, than in grown people, when the eyes of both are exposed to the same degree of light; 1. because in *fætuses* and new-born children, the *cornea* being thicker, less transparent, flatter, and not sufficiently stretched, on account of the small quantity of aqueous humour*, the *retina* is less affected by the rays of light, which are neither freely transmitted to, nor properly collected upon it†; and, 2. because it is probable that

* *Memoires acad. des sciences* 1727. edit. 8vo. p. 348, 349. and 350.

† It has been objected to this, that if in infants vision is indistinct, on account of the *cornea* being thicker, flatter, and less transparent in them than in adults, their pupil ought not to be wider, but more contracted in order to render vision more distinct‡. But as the above mentioned differences between the eyes of new-born infants and those of grown persons do *really* take place, the greater wideness of the pupil in the

‡ See Dr. *Porterfield's Treatise on the eye*, vol. 1. p. 170. and 171.

that they want, in a great measure, the faculty of contracting the pupil, in order to the more distinct vision of near objects, which seems, like the uniform motions of the eyes, to be partly acquired by habit. The causes, therefore, to which the contraction of the pupil are owing, being weaker in new-born infants than in adults, it is no wonder that this passage appears more dilated in the former than in the latter.

IN old people the pupil becomes less moveable, because the *retina* grows less sensible of the

the former than in the latter shews the fallacy of this reasoning ; and at the same time demonstrates, that the eyes being full and plump, or much distended with the aqueous and other humours, cannot be the cause of the wideness of the pupil in new-born children ; as the learned Dr. *Porterfield* would make us believe || : On the contrary, as *Petit* has observed, the *cornea* which is a good deal flat at birth, becomes afterwards more prominent, by the increase of the quantity of the watry humour. I shall only add, that when objects are not clearly seen, because the rays of light are not transmitted to the *retina*, on account of an opacity of the crystalline, watery humour, or *cornea*, the pupil is not contracted to remedy this defect, as it is, when objects are seen indistinctly, on account of their being placed either too near, or too far from the eye.

the *stimulus* of light, and the muscular fibres of the *iris* lose in part their contractile power: further, in old age, the *cornea*, on account of the decrease of the aqueous humour, loses its brilliancy; whence the *retina* will be less affected by light, and consequently the pupil would become wider, were it not that this is more than compensated by the diminished elasticity of the longitudinal fibres of the *uvea* and by the eye becoming less, in consequence of a diminution of the quantity of its humours, whence the diameter of the *circulus albus*, to which the *uvea* is attached, being lessened, the aperture of the pupil must become narrower.

THE motions of the pupil from light, differ from those which are performed in order to render vision less indistinct; since the former are owing to an uneasy sensation affecting the *retina*; whereas the latter arise from an act of volition, or effort of the will in order to the more distinct vision of objects at certain distances. The former are of the same kind with the contraction of the diaphragm in the hiccup and in vomiting, of the muscles of respiration in sneezing, and

and of the *acceleratores urinæ* in expelling the *semen*. The latter agree with the motions of the crystalline, by which the eye is adapted to see distinctly at different distances, and with the uniform motions of the eyes in looking at objects. The first are always necessary and independent of the will; but the second are plainly voluntary, and can be restrained if we please, though they are often not attended with consciousness of volition.

IN looking at near objects, the pupil is lessened, at the same time that the crystalline humour is brought forward towards the *cornea*, by the contraction of the ciliary processes; but when we contemplate more distant ones, the contraction of the ciliary processes and orbicular muscle of the *uvea* ceasing, the crystalline returns to its natural situation, and the pupil to that size to which it is fixed by the quantity of light applied to the eye. These motions though both voluntary, yet come to be so connected by habit, that we cannot perform them separately; nay, as often as we direct our eyes to any near object, the motion of the crystalline

stalline and contraction of the pupil naturally go along, and are performed in such a degree, as is most proper to procure distinct vision at that particular distance: nor can we separate these three motions; although, as they are all voluntary, they may be restrained or performed at pleasure.

THE pupil differs from the *anus*, neck of the bladder, and other passages guarded by *sphincters*, in being always dilated when nothing adventitious acts on the eye, while the latter, left to themselves, are constantly contracted; the reason of which is, that the natural and equable contraction of the longitudinal fibres of the *uvea*, which serve to dilate the pupil, is strongest, while the contrary holds true of the other passages now mentioned, whose *sphincter* muscles have either no proper antagonists, or such as are much weaker than themselves. Further, after death, when these *sphincters* are relaxed, and consequently their passages rendered more patent, the pupil becomes sensibly less, because the longitudinal fibres of the *iris*, to whose contraction its dilatation was owing, lose their contractile power,
grow

grow flabby and longer. Hence we see, that at death the eye-lids remain partly open, for the same reason that the pupil is lessened after it.

IF, from any cause, the longitudinal fibres of the *uvea* are rendered quite paralytic, while its circular muscle retains its usual power, the pupil will, by the natural contraction of the latter, be at all times very much contracted, so that in a bright light it will become little less than in the shade. If the circular, as well as longitudinal fibres of the *iris*, are entirely paralytic, the pupil will be altogether destitute of motion, and much in the same state that it is some time after death, *i. e.* it will be generally as much contracted as the pupil of a sound eye is in a moderate degree of light. If the muscular fibres of the *iris* are not wholly deprived of their contractile power, but greatly weakened, the pupil in a dark place will have its edges a little retracted by the action of the longitudinal fibres, and in a bright light will be somewhat lessened by the contraction of the circular ones; but these mo-

tions will be much more inconsiderable than in a sound eye.

IN all the cases now mentioned, the disease called by *Hippocrates*, and others among the ancients, *ἡμεραλωπία*, will happen, *i. e.* the patient will see in the day-time, but in the twilight and night-season, he will not be able to distinguish objects. An instance of this I had lately occasion to see in a young man of about 27 years of age, who had served for some time in the navy, where he had been exposed to much fatigue and cold: his eyes appeared sound; nor could I observe that they differed from the eyes of other people, excepting that the pupil had very little motion: it remained always pretty narrow, and was neither remarkably contracted by light, nor dilated in the dark. This person saw well enough in the day-time, especially if the weather was serene; but in the twilight, or in an obscure place, was so far from distinguishing objects, that he could scarcely find his way: as his pupil had some motion, it is probable, that the fibres of the *iris* were not quite paralytic, though greatly debilitated: his seeing in
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the day-time shewed, that the *retina* was either wholly, or in a great measure, sound; and that his blindness in a faint light, was owing to the pupil's not being dilated so as to admit a sufficient quantity of rays into the eye.

IF, after an inflammation of the *iris*, a rigidity is left on its circular or longitudinal fibres, the pupil will be deprived, either wholly, or in a great measure, of its usual motions; and may be either too much contracted, or greatly dilated: if the former, the patient will only see well by day; if the latter, the eye will not be able to bear a bright light, and therefore the patient will see best in the shade and by candle light; *i. e.* he will labour under the disease called *μυταλωπία*.

ALTHOUGH in an *amaurosis* the pupil is generally very wide, yet this is not always the case; for as often as the fibres of the *uvea* are entirely deprived of their contractile powers, the pupil appears as much or rather more contracted than in a sound eye. Of this I saw an instance, not long ago, in a woman who was almost totally blind of both

both eyes, where there was no opacity in the *cornea* or crystalline humour, but only a want of motion in both pupils. The pupil of the right eye was immoveable, and always as much contracted as it should have been in a moderate light; the other was dilated, as is usual in a *gutta serena*, but when exposed to the light seemed to contract a very little. By means of this eye she discerned light from darkness, but could not distinguish objects: with the other eye she saw nothing.

IN this patient both eyes seem to have been affected with a *gutta serena*; in the right eye the *retina* was not only insensible, but the muscular fibres of the *uvea* must have been quite paralytic, whence the pupil remained always moderately contracted, as *Winflow* has commonly observed it sometime after death*. In the left eye the *retina*, though considerably diseased, was not wholly destitute of feeling, and the fibres of the *uvea* seem to have been sound and possessed of their usual contractile power.

Of

* *Memoirs acad. sciences* 1721, edit. 8vo. p. 416.

Of the motions of the muscles of the internal ear.

AS, without the motions of the pupil, the eye would have been ill contrived for vision in different degrees of light, and at different distances; so the ear would have been unfit for hearing distinctly a diversity of sounds, were not some of its parts capable of various degrees of tension. A musical chord, of a determinate length and tension, can only vibrate harmonically with one particular sound; if therefore there was no mechanism, by means of which the membranes of the *tympanum* and *fenestra ovalis* could be more or less stretched or relaxed, they could only be harmonically affected by one sound; which, therefore, alone would be heard distinctly, and all others more or less confusedly. To prevent this inconveniency, the *malleus* is furnished with three muscles, and the *stapes* with one; by the various contractions of the former, the membrane of the *tympanum*, and by means of the latter, the membrane of the *fenestra*

fenestra ovalis, is rendered more or less tense, and so accommodated to almost all possible sounds.

It may well appear wonderful, how the ears should be so exactly adapted by the various contractions of these muscles, to such a vast variety of sounds; but with what exquisite skill and amazing wisdom, is every thing in the animal frame adjusted! —

As the *stimulus* of light upon the *retina*, and the sensation of indistinctness in near objects, excite the mind to contract the pupil, so the less distinct *tremor* of different sounds, affecting the auditory nerves, is the cause of the subsequent contractions of the muscles of the internal ear; for no sooner does the mind perceive the first indistinct noise of any sound, but it instantly contracts some of the above muscles, so as most nicely to adapt to it the membranes of the *tympanum* and *fenestra ovalis*: if the sound be acute, these membranes are just as much stretched as is necessary for their vibrating harmonically with it; if it be flat, they are duly relaxed: and thus, by a most simple mechanism, the ear is rendered sensible of
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the smallest variations of sound or difference of notes in musick. As infants seem, by habit, to acquire a faculty, or at least a greater dexterity of adjusting their eyes, by the motions of the pupil and crystalline humour, to the various distances of objects, so it is not altogether improbable, that they may at first hear less distinctly, till, by degrees, they come to acquire a power of readily accommodating their ears more exactly to different sounds. And is not the want of an EAR (as it is usually called) owing to a deficiency of this power*? While that exquisite discernment of musical sounds, which many possess, shews, that they can adjust their ears to different notes with the greatest accuracy.

THAT the motions of the muscles of the internal ear proceed from the mechanical action of sound or vibrating air on their fibres, the analogy of the motions of the pupil forbids us to believe. Further, if this was the case, why should not all the muscles
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* This may arise either from a less degree of sensibility in the auditory nerves, or of agility in the muscles of the ear, or from both.

of the *malleus* be equally contracted by the same sound? And why should those which serve to stretch the membrane of the drum, be excited into motion by acute sounds, while the muscle which relaxes it, is only brought into action by grave ones? —As brute animals upon the first perception of any noise, turn their external ears towards the place from whence it comes, so, at the same time, they adapt their internal ear to it; the first of these motions cannot be denied to flow from their sentient principle actuated by the sound; why then should we doubt that the latter proceeds from the same cause?

THE motions of the muscles of the internal ear in consequence of various sounds, are not only unattended with any consciousness of volition, but are altogether involuntary, for we cannot move them except when sound strikes the ear, nor hinder them to act when it does.

S E C T.

S E C T. VIII.

Of the alternate motions of respiration.

RESPIRATION is that action whereby a certain quantity of air is alternately received into the lungs and expelled out of them : it consists of inspiration and expiration. Inspiration, or the reception of air into the lungs, is owing to the contraction of the *intercostal muscles* and *diaphragm*, whereby the cavity of the *thorax* is both lengthened and widened ; for as the lungs, together with the heart, &c. perfectly fill the cavity of the breast, and as their exterior surface is every where contiguous to the *pleura* and *diaphragm**, it necessarily follows,

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that

* Some authors, I know, contend, that the lungs are not contiguous to the *pleura*, and that, in the space between them, there is contained, what they call internal air, the use of which in respiration, they are at great pains to shew ; but the arguments, upon which this opinion is founded, are no ways conclusive, and might be easily refuted, were it not foreign to our present design ; nor is the authority of the accurate *Morgagni* here of any weight †, since the best Anatomist may

† *Adversar. anat. 5. animadver. 33. p. 46.*

that when the *diaphragm*, by its contraction, descends, and the ribs, by the action of the intercostal muscles, are raised, the lungs must follow them, and consequently the external air must rush in by the *glottis*, to fill the vacuity that would otherwise happen in the cavity of the chest.

INSPIRATION being thus performed, the inspiratory muscles are relaxed, upon which the ribs by the renitency of their elastic cartilages return to their former situation, and the diaphragm, by the reaction of the stretched *peritonæum*, *pericardium*, and abdominal muscles, is pushed up into the *thorax*; whose cavity being therefore diminished, the air contained in it, must be expelled by the *glottis* *.

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may be deceived in making a single experiment, and since we have the repeated experiments of some of the greatest Anatomists against him; nay in every dead body, where the integuments and intercostal muscles are carefully taken off, the lungs may be seen contiguous to the *pleura*.

* While the cavity of the *thorax* is lessened by the causes here mentioned, the muscular fibres of *bronchia*, by their contractile power, contribute to the expulsion of the air out of the lungs.

IN order to account then for the alternate motions of respiration, it is only necessary to shew, why the intercostal muscles and diaphragm are alternately contracted, and relaxed, since their contraction occasions inspiration, and their relaxation allows the elastic force of the cartilages of the ribs, &c. to produce expiration *. But as Mr. *Bremond* has, in the *memoires* of the *acad.* of *sciences* for 1739, favoured us with a set of pretty extraordinary experiments, which, he thinks, clearly prove, that the lungs are not passive in the affair of respiration, but are endued with a power of dilating and contracting themselves, independent of the motions of the *thorax*; it will be necessary, before we proceed any further, to shew, how far this ingenious Gentleman has been deceived; and that the lungs have really no proper

* If any one doubts of both rows of intercostal muscles conspiring to pull up the ribs, he need only compare what *Winslow* has said on this head (*anat. sect. 3. N° 1057, 1058, 1059.*) with the course and direction of these muscles in a fresh subject, or if that cannot be had, with the elegant figures of them published by *Dr. Headly* at the end of his lectures on respiration.

proper alternate motion of their own, but follow the motions of the chest.

OF the experiments related by Mr. *Bremond*, the following are the most remarkable.

1. AFTER a wound made in the *thorax* of a dog, the lungs, instead of collapsing, continued to be contracted and dilated alternately, but their motions were asynchronous to those of the *thorax*; for when the ribs were depressed, a small portion of the lungs was thrust out at the wound with a considerable force*.

2. AFTER making an opening in the breast, and breaking four or five of the ribs, the lungs continued for some time to be alternately expanded and contracted; and issued, always, out at the wound, when the *thorax* collapsed†.

3. AFTER three ligatures were made upon the *trachea* of a dog, and the *thorax* was opened, the alternate motions of the lungs

* *Memoires acad. des sciences* 1739, edit. 8vo. p. 463. and 465.

† *Ibid.* p. 464. and 465.

lungs were observed to go on very briskly; but they appeared to be dilated, and issued out at the wound when the chest was contracted, and *vice versa* *.

HOWEVER difficult it may be thought, at first sight, to account for the appearances in these experiments, yet it is easy to shew, that the lungs cannot possibly be endued with a power of expanding themselves, independent of the dilatation of the *thorax*, as Mr. *Bremond* seems to think, after *Platerus*, *Sennertus*, and others, who in this followed the doctrine of the *Arabian* physicians.

As the lungs are composed of an infinite number of vesicles and cellular interstices †, which are partly made up of elastic contractile fibres, 'tis easy to perceive that when distended with air, they must endeavour to reduce themselves to their former bulk; but, supposing the vesicles of the lungs empty and collapsed,

* *Memoires acad. des sciences*, p. 468.

† The reader may easily see, that our reasoning here is of equal force, whether the lungs are supposed entirely cellular, with *Helvetius* *. or partly vesicular partly cellular, with *Winflow* †.

* *Memoires acad. des sciences* 1717, edit. 8vo. p. 30. 31. &c.

† *Anatomie*, sect. ix. No. 105. 106. 107.

collapsed, by what mechanism can they expand themselves, or where are the antagonist muscles that can overcome the natural contraction of their fibres? All the hollow muscles of animals are continually endeavouring to contract, nor can they be dilated by any mechanism of their own: thus the bladder of urine, which may aptly enough be compared to a single vesicle of the lungs, spontaneously contracts itself, when the urine is evacuated, and would for ever remain in this state, were it not dilated by the urine following anew into it. In the same manner the stomach and intestines, which are hollow muscles, have nothing in their structure by which they can expand themselves: they are ever endeavouring to arrive at their least capacity, and are only prevented by the aliment, air, and other fluids contained in them. It follows, therefore, that the pulmonary vesicles and cells, which are composed of elastic contractile fibres, cannot possibly be dilated by any power or action of their own.

BUT further, if Mr *Bremond's* experiments prove any thing, the lungs have not only

a power of inspiring air by the *trachea* ; but, although this fluid is denied its usual access by the *glottis*, can expand themselves alternately, notwithstanding the pressure of the atmosphere upon their external surface resisting such expansion ; which is much the same as if one should affirm, that a bladder perfectly empty, with a tight ligature about its neck, could, by its own proper power, swell and overcome the pressure of the external air.

HAVING shewn that the lungs cannot possibly be endued with a power of expanding themselves, it remains, that we now inquire, to what causes their apparent motions, in *Bremond's* experiments, were owing.

IN the two first experiments above mentioned, when the cavity of the *thorax* was enlarged by the action of the inspiratory muscles, a small portion of air would be received by the *glottis* into the lungs of the wounded side : but as this could bear no greater proportion to the air entering by the wound, than the aperture of the *glottis* did to this opening, the ribs would at that time

time recede from the lungs, which therefore would seem to subside.—When the *thorax* collapsed, the air contained betwixt the ribs and the surface of the lungs escaping by the wound, the lungs would soon become contiguous to the ribs, and even part of them would be pushed out at the opening, not only on account of the convulsive contraction of the *thorax* squeezing the lungs much more than in ordinary expiration, but partly from the small quantity of air received by the *glottis* during the former inspiration, and not yet wholly expelled, which being rarified by the heat of the lungs, must considerably increase their bulk.

THE apparent contraction therefore of the lungs, when the dogs endeavoured to inspire, remarked by *Bremond* in his experiments, is wholly to be ascribed to the enlargement of the *thorax*, which at this time rises from the anterior surface of the lungs; while they, following the diaphragm now strongly drawn down towards the *abdomen*, really recede from the *sternum*. And if, during expiration, upon the ribs being depressed

fed, and the diaphragm being forcibly thrust up into the cavity of the breast, by the strong convulsion of the abdominal muscles, the lungs really appeared to swell, and some portion of them was even forced out at the aperture made in the *thorax*; yet this ought not to be attributed to an expansion of the lungs happening at this time, but rather to the subsiding of the ribs and the protrusion of the diaphragm into the chest, whose cavity being therefore greatly diminished, the lungs (in some degree inflated) not only fill it, but being pressed on all sides, are thrust out at the wound, where there is least resistance; as soft clay, leaven or such like substances when strongly squeezed in the hand, are forced through the interstices between the fingers.

BUT further, while the *thorax* is wounded only on one side, the lung of the other side continues to follow the motions of the chest as usual, and to be alternately inflated with air rushing into it by the *glottis* *: when therefore, during expiration, the air is forcibly expelled out of this lung, altho'

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* *Higmore* disquisit. anatom. p. 188.

the greatest share of it escapes by the *glottis*, yet, since fluids press equally every way, some part must enter the large branches of the *trachea* which belong to the lung of the wounded side, and consequently dilate it; and this the more remarkably, as the animal in howling contracts its *glottis* more or less, and so renders the egress of the air through it more difficult; hence, during expiration, this lung will appear to swell considerably, and part of it will be pushed out at the opening in the *thorax*, not only as its cavity is at this time greatly lessened, but as the lung itself is really in some degree inflated: 'tis plain however, that even this inflation is owing to the contraction of the *thorax* forcing the air out of the lung of the sound side.

THIS is further confirmed by an observation of Dr. *Houston*, who tells us, that when the dog howled, his lungs burst out at the wound, but when he was silent, they retired within the *thorax**; and seems to be put beyond doubt, even by an experiment of *Bremond*'s own making, in which altho',
after

* Philosophical Transactions abridged, vol. 9. p. 141.

after making an opening into one side of the *thorax*, and breaking three or four ribs, the lungs were pushed out at the wound, every time the breast was contracted; yet, as soon as the anterior part of the *thorax* and *sternum* were raised, and both sides of the breast thus laid open, the lungs instantly collapsed, and remained so without any motion, notwithstanding the heart, ribs and diaphragm continued their alternate motions for some time*.

DR. *Higmore*, who speaks of the number of his experiments made upon dogs, in order to satisfy himself concerning the manner in which respiration is performed, as having almost threatened the entire destruction of that species of animals, observes, that when both sides of the *thorax* had large wounds made in them at once, the lungs always collapsed † : nay there is not one of the many experiments related by *Bremond* himself, in which the lungs were pushed out of the *thorax*, when both sides of it were opened.

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* *Memoires acad. des sciences*, 1739, edit. 8vo. p. 464.

† *Disquisit. anatom.* p. 188.

IT must be owned indeed, that, in two experiments of the *Baron Van Swieten*, the lungs did not collapse, after both sides of the *thorax* were perforated, but were protruded through the apertures, during expiration*. However, it is to be observed, that the wounds seem to have been but small; since he afterwards adds, that when the opening in each side of the *thorax* parallel to the ribs, was half an inch or more in length, the animals quickly died. Further, while the animals lay quiet, the lungs kept within the cavity of the breast, and were only thrust out of the wounds, when, on account of pain, they made great efforts; and since in straining, or any violent motion of our muscles, we always contract the *glottis*, and retain the inspired air in the *thorax*, it is more than probable, that the eruption of the lungs through the wounds, in expiration, was owing to the air being retained in them while the *thorax* collapsed. Lastly, the *Baron Van Swieten* observed, that during inspiration the orifices of the wounds became less patent, by the ribs being drawn nearer

* Comment. in *Boerhaav.* aphor. tom. 1. p. 271.

nearer one another, so that a less quantity of air would enter by them, and a greater proportion by the *glottis*: hence the lungs did not collapse; as always happened in *Higmore's* experiments, when very large openings were made at the same time in both sides of the *thorax*; but when a hollow tube, whose aperture greatly exceeded that of the *glottis*, was introduced into the wound of each side, the lungs instantly subsided, respiration ceased, the voice failed, and the dog seemed to die *.

WITH regard to the *phenomena*, in experiment 3d above mentioned, it ought to be observed, that the lungs in a natural state, equally fill the cavity of the *thorax* in inspiration and expiration; if therefore we suppose the lungs to have been in a middle state of distension, when Mr. *Bremond* made his ligatures on the *trachea*, their bulk must have been considerably less than the cavity of the *thorax* when most enlarged, but at the same time greater than this cavity when the chest is violently contracted: so that we ought not to be surpris'd, if, upon the elevation

* Commentar. in aphorism. *Boerhaav.* tom. 1. p. 271.

elevation of the ribs and depression of the diaphragm in inspiration, the lungs appeared to subside, and no longer filled the *thorax*, or if, upon the constriction of the breast in expiration, they seemed to swell, and part of them was pushed out at the wound.

BUT though we suppose the *trachea* to have been tied during inspiration, yet since *Bremond* found, notwithstanding the ligatures, that after the dog's death, a small quantity of air blown forcibly through the *trachea* passed into the lungs, it is not improbable that the diaphragm and ribs strongly squeezing the lungs in expiration, had forced out part of the air contained in them through the wind-pipe, so as to have reduced them to a moderate state of expansion.

LASTLY, if we should suppose the ligatures to have been made even about the end of expiration, yet the air remaining in the lungs, being rarified by their heat, would soon increase their bulk to such a degree, as that, when the *thorax* was greatly contracted, part of them must necessarily be pushed out at the wound. Perhaps also,

also, during the enlargement of the *thorax*, a small quantity of air might, notwithstanding the ligatures, be received by the *trachea* into the lung of the sound side, which, upon expiration, would be chiefly pushed into the lung of the wounded side, since its egress by the *glottis* would be very difficult, on account of the ligatures on the *trachea*.

THAT the apparent motions of the lungs in the above experiments of *Bremond*, were, in fact, chiefly owing to the motions of the *thorax*, particularly to the alternate depression and ascent of the diaphragm, an experiment related by this writer himself must convince us; for we are informed by him, that the *abdomen* of a living dog, being laid open, and a hole made in the fleshy part of the diaphragm on the left side, the lung of this side instantly collapsed, and remained without any motion, although the *thorax* continued to be alternately dilated and contracted for a considerable time*. Now, if the lungs were endued with a power of expanding and contracting themselves, why did the lung of that side, where the diaphragm

* *Memoires acad. des sciences*, 1739, edit. 8vo, p. 471.

phragm was perforated, immediately collapse and cease to move? Besides, does not this experiment shew, that the apparent motions of the lungs, and their egress by the wounds, were chiefly owing to their being alternately pushed up into the cavity of the *thorax*, when the diaphragm was relaxed? That the ascent of this muscle into the chest, by the convulsive contraction of the abdominal muscles, especially when the dogs attempt to howl, contributes much more to the apparent swelling of the lungs and their issuing out of the *thorax* during expiration, than the falling of the ribs, is evident from another experiment of *Bremond*, who observed these motions of the lungs to continue, although, with his hands, he forcibly hindered the ribs of the wounded side from moving, and consequently from pressing the lungs alternately*.

Bremond always observed, that when the ribs were elevated, the lungs appeared red, but became paler when the cavity of the breast was diminished †. The lungs being
no

* *Memoires acad. des sciences* 1739, p. 482.

† *Ibid.* p. 483.

no longer pressed while the *thorax* was enlarged, admitted the blood from the right ventricle of the heart more readily into all their vessels ; but being strongly compressed by the ascent of the diaphragm and depression of the ribs, this blood must in part be expelled ; when of course they become paler.

WHAT has been said above, may serve also to shew how far Mr. *Herissant* is mistaken, when, from some experiments of a like nature with those of *Bremond*, he concludes, that the apparent alternate dilatation and contraction of the lungs in animals whose *thorax* is laid open, is owing, solely, to the blood pushed into the pulmonary artery by the right ventricle of the heart, which, by dilating and unfolding all its branches and ramifications, must make the whole substance of the lungs swell, and cause the air to rush into their vesicles by the *glottis* *.— If this account of the matter were just, the alternate swelling and falling of the lungs would be very inconsiderable, and ought to correspond with the contraction and dilatation of the heart ; which however is not the

A a case.

* *Histoire acad. des sciences* 1743, edit. 8vo. p. 103.

case. Besides, it ought not to be observed at all, when the passage of the air into the vesicles of the lungs is obstructed by ligatures made on the *trachea*, contrary to what happened in *Bremond's* experiments.

THUS much being premised, to shew that the lungs have not properly any inherent power by which they can alternately contract and dilate themselves, but that, in ordinary and healthful respiration, they always follow the motions of the *thorax*, we proceed next to inquire, by what power or mechanism, inspiration and expiration alternately succeed each other, or why the intercostal muscles and diaphragm are contracted and relaxed by turns, as long as life remains.

THE learned *Boerhaave*, in order to account for the alternate motions of the *thorax* in respiration, supposes, that, at the end of inspiration, the blood is transmitted in smaller quantity to the left ventricle of the heart, since the pulmonary vessels must be considerably compressed by the lungs, which, at that time, are greatly distended with air: hence he conceives, that not only less blood will be distributed to the intercostal

costal muscles and diaphragm, but, also, that the influence of their nerves must be weakened; as the secretion of the spirits in the *cerebellum* must be diminished, when a smaller quantity of blood is pushed into its vessels by the heart: the causes, therefore, which are supposed to contract the inspiratory muscles, being weakened at the end of inspiration, these muscles will be overcome by the natural resiliency of the elastic cartilages of the ribs, together with the reaction of the abdominal muscles, &c. *i. e.* expiration must necessarily follow; but no sooner does the blood, by the motion of the lungs in expiration, flow in a more plentiful stream to the left ventricle of the heart, than the causes actuating the inspiratory muscles begin to be increased; whence these muscles are contracted anew, *i. e.* inspiration is produced, to which, for the reasons above mentioned, expiration must necessarily succeed; and in this way the alternate motions of the chest in respiration are carried on through the whole of life *. This theory, it must be owned, is very ingenious, and has an air of simplicity which cannot

not

* *Boerhaave institut. med. § 619 & 620.*

not fail to recommend it ; but if strictly inquired into, will be found altogether insufficient to account for the alternate motions of the *thorax*, or to answer the *phænomena* of respiration. For,

1. IF at the end of inspiration the intercostal muscles and diaphragm were relaxed, on account of the smaller quantity of blood and spirits then distributed to them, why should not the heart, which also receives its nerves from the *cerebellum*, be affected in the same way? If the secretion of vital spirits were diminished, on account of less blood's flowing from the lungs to the left ventricle of the heart at the end of inspiration, how could the pulse be then equally strong as at the end of expiration? which however is the case, as far as our sense of feeling can determine. But,

2. ALTHOUGH we should grant, that at the end of inspiration the blood flows in a smaller stream to the left ventricle of the heart, yet it will by no means follow, that the *cerebellum* will cease to supply the vital
organs

organs with spirits sufficient for their alternate motions; since we know, that after both the carotid arteries have been tied in a dog, the motions of the heart and respiration went on in the ordinary way, while in the mean time the *cerebrum* and *cerebellum* were deprived of more than one half of the blood usually bestowed upon them*.

3. AFTER the lungs have been kept for some considerable time in a collapsed state by an effort of the will, the inspiratory muscles are no sooner left to themselves, than immediately they contract, and produce a new inspiration; which, however, could not possibly happen if *Boerhaave's* theory was true, since, in this case, the blood must flow with more than ordinary difficulty through the pulmonary vessels, and consequently the causes actuating the inspiratory muscles must be greatly weakened†.

BUT,

* *Van Swieten* comment. in *Boerhaav.* aphor. vol. 1. p. 266.

† This argument must conclude with the greater force, since even *Boerhaave* himself allows, that the blood passes less freely through the lungs when they are collapsed than when

BUT, 4. The insufficiency of this account of respiration, is demonstrated beyond doubt, by the experiments of *Higbmore* and *Bremond*, who tell us, that, after both sides of the *thorax* were laid open, the diaphragm and intercostal muscles continued their alternate contractions for a long time altho' the lungs were collapsed and without motion *. Here we find the motions of inspiration and expiration continued in the *thorax*, while the lungs remained always in the same state, and when there was no cause which could make the blood flow alternately through the pulmonary vessels with greater or less ease, nor consequently render the inspiratory muscles alternately paralytic, through a defect of blood and spirits.

5. LASTLY

when they are inflated. “ Pulmone per aerem distento, sanguini pulso ex cordis dextro thalamo, latiora vasa arteriosa, et venosa, minus resistunt, transitum expediunt; faciunt ut omnis ille rapiatur eo quam celerrime ventriculum sinistrum versus: collapsus idem vix per arteriam pulmonalem impleri potest liquore impulsio; inflatus per vasa aerifera, facile sanguiferorum impletionem patitur.” *Boerh.* institut. med. § 200. No 2.

* *Higbmore* disquisit. anat. p. 185. et Memoires acad. des sciences 1739, edit. 8vo. p. 464. 467, 468.

5. LASTLY, The various *phænomena* of respiration, in the air-pump, diseases of the head, *asthma*, and in melancholy people, are not to be accounted for from *Boerhaave's* theory, and are alone sufficient to overturn it: but of this more afterwards.

THE late ingenious Dr. *Martine*, aware of the difficulties attending *Boerhaave's* account of respiration, has proposed the alternate compression of the phrenic nerves at the end of inspiration, as the cause which, at that time, renders the diaphragm paralytic, and consequently produces expiration: he seems indeed to doubt, whether the alternate pressure of the inflated lungs on the posterior part of the *pleura*, can, at the end of inspiration, intercept the influence of the nerves belonging to the intercostal muscles which lie behind it: but as the phrenic nerves run between the lungs and *pericardium*, and are only covered by the thin *mediastinum*, he thinks, that, at the end of inspiration, when the lungs are much distended with rarified air, these nerves must undoubtedly suffer such a remarkable compression, as to render the diaphragm to which they

they are distributed paralytic*. But this account of the motions of respiration, however ingenious, will be found still more defective and less satisfactory than *Boerhaave's*, which we have already rejected.

1. THIS account of respiration must at best be allowed to be defective, as it does not inform us how the intercostal muscles come to be alternately contracted, as well as the diaphragm. — It is by no means probable, that the nerves of the intercostal muscles can suffer any more compression than usual at the end of inspiration; nor would it serve the Doctor's purpose to suppose they do, since he seems to agree with those who are of opinion, that the two orders of intercostal muscles are antagonists to one another, and consequently are contracted at different times.

2. SINCE the Doctor allows, that during inspiration the nerves become rather freer from compression, why should not the diaphragm remain contracted, and consequently the lungs continue in their most expanded state?

* *Edinburgh Medical Essays*, vol. 1. art. 12.

state? He says indeed, that the inspired air, rarified by the heat of the breast, and not finding an exit free or wide enough by the *glottis*, will at this time press more upon the vesicles and membranes of the lungs; which pressure must be communicated to the phrenic nerves running along the *pericardium*, and which are covered only by the *mediastinum*.

BUT surely the rarefaction of the inspired air at the end of inspiration, is not so remarkable or sudden, but that it can issue fast enough out by the aperture of the *glottis*, to preserve it in *æquilibrio* with the external air: besides, as inspiration does not immediately follow expiration, but after a short pause, ought not the air contained in the lungs at the end of expiration to be rarified, and so produce the same effect, by its pressure upon the vesicles of the lungs and phrenic nerves, as at the end of inspiration? The Doctor, it is true, seems to have been aware of this; and therefore supposes, that, at the end of expiration, the contractile fibres and membranes of the lungs, will, by their reaction, prevent, in some measure,

the inflating air from pressing with its whole force on the phrenic nerves. But will not this hold equally true at the end of inspiration? and will not the elastic fibres and membranes of the lungs react with much greater force when they are remarkably stretched by inspiration, than when they are considerably relaxed at the end of expiration? As the lungs, therefore, both in expiration and inspiration, equally fill the cavity of the *thorax*, the compression which the phrenic nerves suffer from them, will be pretty much the same at the end of expiration, as in a state of full inspiration; and consequently the difference of this pressure cannot account for the alternate motions of the diaphragm to which they belong.

3. If, at the end of inspiration, the phrenic nerves suffered such compression from the inflated lungs, as to render the diaphragm paralytic, how comes it to pass, that, after a full inspiration, we can, by an effort of the will, keep this muscle, for a considerable time, in a strong state of contraction, and thus hinder expiration from following inspiration?

4. FURTHER,

4. FURTHER, in one of Mr. *Bremond's* experiments, where the lungs remained collapsed and without motion, and consequently where the phrenic nerves must have been exposed to an equal degree of compression, the intercostal muscles and diaphragm continued to be alternately contracted and relaxed for above a quarter of an hour*.

5. THAT the motions of respiration vary according to the quantity or quality of the blood thrown into the pulmonary artery, to the free or difficult passage it meets with in the vessels of the lungs, and to the heat or coldness, rarity or density of the air, are circumstances of great truth and importance, but utterly inexplicable upon this theory.

6. LASTLY, N^o 2. 3. 4. and 5. of the arguments mentioned in Sect. II. to shew that the alternate motions of the heart cannot be owing to the compression of the nerves, are here of equal, yea of greater force; for the soft and spongy lungs are much less capable, even when inflated, of compressing

* *Memoires acad. des sciences* 1739, p. 468.

compressing the nerves, than the firmer arteries and auricles of the heart.

THE various opinions of other writers, I shall not stay to enumerate, much less undertake to refute; but proceed to give an account of the motions of the *thorax*, which it is hoped will tend equally to explain the appearances observed in respiration, whether the lungs and other instruments concerned in it, be in a natural or diseased state.

I. DURING inspiration and expiration, the blood finds an easy passage through the vessels of the lungs, as by their alternate inflation and contraction, it is pressed forward to the left ventricle of the heart. After inspiration is completed, it begins to flow with more difficulty; and at the end of expiration (if inspiration does not soon succeed) its motion is still less free. After expiration, therefore, the blood, on account of its difficult passage through the pulmonary vessels, is partly accumulated in them, and, by stretching their sensible fibres and membranes, acts as a *stimulus* upon the pulmonary nerves, occasioning an uneasy sense of

of fulness, stoppage, or suffocation in the breast, which is more or less remarkable, according to the time during which respiration is stopt, the capacity of the pulmonary vessels, and the quantity of blood thrown into them by the right ventricle of the heart.

THAT a *stimulus* affecting the heart and alimentary canal, should be the cause of their alternate contractions, as we have shewn above, is no ways improbable, the irritating cause being applied immediately to the organ to be moved; but that the diaphragm and intercostal muscles should be brought into contraction, by a *stimulus* acting upon the lungs, may at first appear somewhat extraordinary, though, upon further consideration, we may assure ourselves of the certainty of the fact, from the strongest and justest analogy. — Thus, for example; if a few drops of water, or any other liquor, by an accident in swallowing, fall into the *trachea*, the diaphragm and intercostal muscles are instantly brought into action, and continue to be agitated with alternate contractions and relaxations, till the stimulating

stimulating cause is removed. — Again, if a thin humour secreted in too great quantity, by the vessels and glands of the *bronchia*, distills upon the vesicles of the lungs, alternate convulsions of the diaphragm, intercostal and abdominal muscles ensue; which are repeated over and over again, till the irritating cause is lessened or expelled. — In a true peripneumony also, when, by reason of an obstruction in the pulmonary arteries, the blood passes through the lungs with great difficulty, a short cough is almost a constant symptom. Is it not therefore reasonable to infer, that a less remarkable *stimulus* or uneasy sensation in the vessels of the lungs, will be followed by gentler contractions of the inspiratory muscles?

AFTER expiration is finished, the blood beginning to be accumulated in the lungs, will, not only by its quantity stretching their vessels, but also by its heat, occasion an uneasy sensation, that is, act upon these parts as a *stimulus*; in consequence of which the diaphragm and intercostal muscles are contracted, and inspiration is performed; by which the blood being not only cooled by
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the external air, but its passage being also promoted towards the left ventricle of the heart, the *stimulus* or uneasy sensation ceases: hence these muscles are relaxed; and consequently, by the reaction of the cartilages of the ribs, and the stretched abdominal muscles, &c. the cavity of the *thorax* is lessened, *i. e.* expiration is performed; which, on account of the disagreeable sensation which begins to be felt in the lungs, is soon succeeded by a new inspiration.

ALTHOUGH, in ordinary breathing, we are but little sensible of this uneasiness, arising from the difficult passage of the blood through the lungs after expiration is finished; yet if one attends to it, and restrains inspiration for some time, it becomes very perceptible: and as in asthmatic patients, the laborious contractions of the inspiratory muscles are, beyond all question, owing to an anxiety and sense of suffocation in the breast; so it is highly reasonable to think, that in healthful people, the gentler *stimulus* of the warm blood accumulated in the pulmonary vessels, is the cause of ordinary inspiration.

FURTHER,

FURTHER, a variety of *phenomena* concur to persuade us, that the blood acting as a *stimulus* on the vessels of the lungs, after expiration, is the cause of the succeeding contraction of the diaphragm and intercostal muscles. Thus we observe, that as the blood flows in greater or less quantity through the lungs, inspiration and expiration more quickly or slowly succeed each other. Hence in a smart fever, the breathing is much quicker than in health *, when one lies a-bed; and every one knows how remarkably both the pulse and respiration are accelerated by violent exercise.—Though the quantity of blood flowing through the lungs remains the same, yet if its heat and bulk be increased, respiration becomes more frequent: hence in bagnios, and in the warm summer's air, we breathe oftener, than in our common rooms, and in more temperate rate

* In fevers, we sometimes meet with a very quick pulse, while yet the breathing seems to be scarcely quicker than in health; but in such cases, the pulse is small and quick, and consequently the quantity of the blood passing through the lungs may be very little more than in health; when, altho' the motion of the heart be much slower, yet it throws out more blood at every contraction.

rate seasons.—Again, when any obstruction happens in the pulmonary vessels, which renders the passage of the blood through them more difficult than in health, respiration is more laborious and more frequently repeated: hence the quick breathing in peripneumonies, and other disorders consequent upon the lungs being obstructed.—If a portion of the lungs be rendered useless, or be wholly consumed by an ulcer, the patient is short-breathed and subject to asthmatic fits, upon the least fatigue, or upon any increase of motion or rarefaction in the blood.

SINCE therefore it appears, that the motions of respiration are, *ceteris paribus*, always proportional to the quantity of blood thrown into the pulmonary vessels, and its easy transit through them, this fluid ought undoubtedly to be esteemed the cause which excites, regulates and continues these motions: and since respiration is more frequent and laborious, when a less quantity of blood passes with greater difficulty through the lungs, than when a larger stream flows through their vessels with

more ease ; these increased motions of the *thorax* cannot be owing to the inspiratory muscles being more plentifully supplied with blood and spirits, but must proceed from the *stimulus* or uneasy sensation accompanying the difficult passage of the blood thro' the pulmonary vessels, or its stagnation in them. And does not this plainly shew, why blood-letting gives more speedy relief in fits of difficult breathing, than any other remedy ?

2. If it be asked, how a *stimulus* or uneasy sensation in the lungs can affect the inspiratory muscles, with which they seem to have no immediate connexion ; I answer, It were easy to ascribe this effect to a sympathy between their nerves ; a phrase indeed oftener used than well understood ! but as the pulmonic *plexus* has no greater connexion or communication with the phrenic nerves, and those which supply the intercostal muscles, than with the nerves of the stomach, intestines and other abdominal *viscera*, which are no ways affected by the gentle *stimulus* of the blood as it passes through the pulmonary

pulmonary vessels; I think we cannot fairly ascribe the motions of the inspiratory muscles to any sympathy proceeding from a connexion or communication between their nerves and those of the lungs. Further, as the nerves of the inspiratory muscles and lungs, most certainly, do not terminate precisely in the same part of the brain, but probably in places somewhat distant from each other, any sympathy that obtains between them, as proceeding from one common origin, must be owing to SOMETHING equally present in these several places, *i. e.* to the mind or sentient principle: for without supposing some percipient BEING in the brain, how can an irritation of the extremities of the nerves, taking their rise from one part of that organ, occasion a more than ordinary derivation of spirits into such nerves as have their origin from a different part? If external objects act on the nerves only, by putting a stop to the equable progression of their fluids, or by exciting some vibratory motions in them, how can any of these occasion, not only a more copious derivation of spirits through the nerves thus affected,

affected, but also through a variety of other nerves with which they have no connexion, and whose rise is from a different part of the brain? The sympathy, therefore, or consent observed between the nerves of various parts of the body, is not to be explained mechanically, but ought to be ascribed to the energy of that sentient BEING, which in a peculiar manner displays its powers in the brain, and, by means of the nerves, moves, actuates, and enlivens the whole machine.

BUT further, if the sympathy observable between different parts of the body, be wholly owing to the connexion or communication of their nerves, how comes the pupil to be contracted by the action of light on the *retina*, when the nerves of the *uvea* have not only no communication with the optic nerve, but arise from a pretty distant part of the brain? or, if there were some general sympathy between the nerves, why should not the longitudinal fibres of the *uvea* be contracted, as well as the orbicular ones, and so the coarctation of the pupil be prevented? If the alternate contractions of the
inspiratory

inspiratory muscles were owing merely to their receiving a few nervous twigs from the intercostals, which furnish the *plexus pulmonicus*, why is not the heart and alimentary canal equally affected with them, by a *stimulus* or uneasy sensation in the lungs? why are not the intercostal muscles as much convulsed in vomiting as the diaphragm and abdominal muscles? and why, upon an irritation of the membrane of the nose and *trachea*, are not the abdominal muscles contracted, till the inspiratory muscles begin to be relaxed? These questions will scarce be answered satisfactorily, upon any scheme of sympathy depending wholly on the communication or connexion of nerves; but have no difficulty in them, if the motions now mentioned be referred to the mind or sentient principle.

WHEN, therefore, in consequence of a disagreeable sensation in the lungs, arising from the difficult passage of the blood thro' their vessels soon after expiration is finished, the inspiratory muscles are contracted; we are not to ascribe this to any unknown sympathy acting mechanically upon these muscles

muscles or their nerves; but to the MIND or sentient principle, which being affected by the uneasy perception in the lungs, is thereby excited to increase the action of the nervous influence upon the intercostal muscles and diaphragm; by which the cavity of the *thorax* being enlarged, and the lungs inflated with fresh air, the disagreeable sensation in them is removed; and consequently the extraordinary contraction of the inspiratory muscles ceases: hence, by the reaction of the elastic cartilages of the ribs, abdominal muscles, &c. the cavity of the *thorax* is lessened, *i. e.* inspiration is naturally followed by expiration; which again must soon be succeeded by a new inspiration, on account of the particular sensation which begins to arise in the lungs.

3. IT does not appear, that any effort of the mind or sentient principle is necessary to expiration; for this naturally takes place as soon as the muscles of inspiration cease to act. The reaction of the cartilages of the ribs and stretched *pericardium* and *peritonæum*, are wholly owing to the elasticity of the

the parts, and not to any muscular contraction or additional force communicated to them at this time; nay, the reaction of the abdominal muscles in expiration, seems to be pretty much of the same kind; although it is not improbable, that the extension of their fibres, by the depression of the diaphragm in inspiration, may, as a very gentle *stimulus*, excite in them a true muscular contraction*. However, this irritation prompting the abdominal muscles to contract at the end of inspiration, must be very inconsiderable, and in no ways like the convulsive motions brought on other muscles by a *stimulus*; since, when they are greatly stretched by a very full inspiration, we do not find any difficulty in preventing their contraction, or in moderating it as we please; while, on the contrary, in vomiting their motions are altogether convulsive and involuntary.

* The same thing may be said of the sternocostal muscles, which are generally thought to pull the *sternum* and cartilages of the ribs downwards and backwards in expiration, but which seem scarcely, if at all, to act in ordinary and gentle expiration.

involuntary. Further, the *thorax* of dead animals being in a full state of expiration shews that this is brought about, after all muscular action ceases, by the mere elastic force of the parts. Nor is it any objection here, that when air is blown into the *thorax* of a dead body, expiration is performed more slowly than in a living one; because, by the cold and total stagnation of the fluids, the parts not only become more rigid, and the articulations of the ribs less moveable, but the instruments of expiration lose, in a good measure, their elastic power.

LASTLY, the *phenomena* observable in comatous patients, and which we shall hereafter take notice of, shew, that whereas inspiration is owing to the energy of the sentient principle, and is, therefore, in such patients, in some degree interrupted, expiration is performed as usual; which could not happen, if, like inspiration, it proceeded from the mind, or from any particular sensation directing it to put certain muscles in action; for in that case there ought to be a pause at the end of inspiration, as well
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as at the end of expiration. Upon the whole, therefore, we may conclude, that expiration naturally ensues as soon as ever the inspiratory muscles cease to act, chiefly by virtue of the elasticity of the stretched parts, and scarcely at all by the power of any muscular contraction*.

HERE we may observe a remarkable analogy betwixt the motions of the pupil, and of the *thorax* in respiration. The coarctation of the pupil, when light is admitted into the eye, is owing to the muscular contraction of the circular fibres of the *uvea*, in which, therefore, it seems to correspond with inspiration; but its relaxation when the *stimulus* of light ceases, is produced merely by the natural contraction of the longitudinal fibres of this membrane, and consequently in this it resembles expiration.

D d

4. IF

* What is said here, is only meant of ordinary and gentle expiration, which is performed without consciousness, or the assistance of any of those muscles which act in violent expiration.

4. IF it be demanded, why, after the lungs, by an effort of the will, have been kept for some time in a state of full inspiration, the inspiratory muscles are immediately relaxed, when this effort ceases, and not rather continued in a state of contraction, seeing there is an uneasy sensation in the lungs, equal to what happens after expiration; the answer is, that the disagreeable sensation is of a different kind, and which, the keeping the lungs in a state of inspiration, would tend rather to increase than remove: for such is the constitution of our frame, and the law of that wonderful union connecting the soul and body, that the former, upon any uneasy perception, produces such motions and changes in the latter, as naturally and most effectually tend to lessen it, or expel the irritating cause.— Thus the uneasy sensation arising from the action of light upon the tender *retina*, is not followed by a contraction of the longitudinal fibres of the *uvea*, because this would not have the effect of diminishing, but of adding to the disagreeable perception. For the

the same reason, the mind, in consequence of a *stimulus* or uneasy feeling in the lungs, increases the action of the nervous influence upon the intercostal muscles and diaphragm, and not upon the muscles of the *abdomen*, back, or loins. But further, the continuing the inspiratory muscles for any considerable time in a state of full contraction by a voluntary exertion of the power of the mind, never fails to give some degree of uneasiness; so that it is no wonder, if they be relaxed as soon as the effort of the will ceases.

5. SUDDEN surprize, or any thing that will but for a few moments strongly fix the attention of the mind, prevents the hiccup, if it be from a weaker cause.—Sneezing is stifled in the beginning, whenever an attempt to perform it raises an acute pain in any part of the body; as frequently happens in rheumatisms affecting the muscles of the back or *thorax*. In these cases, the mind, being strongly affected by the acute pain, becomes, in a great measure, insensible of
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the irritation of the olfactory nerves * ; wherefore no violent or convulsive motion ensues.—In the same manner, if there be only a gentle irritation in the *trachea*, any thing that renders the mind less sensible of this, will prevent coughing. Hence, in time of eating, a tickling cough generally ceases, or is less frequent ; for not only the chewing and swallowing of the food engage the attention of the mind at that time, but the motions of the *larynx* in deglutition have almost the same effect in lessening the sense of irritation in the *trachea*, as friction has in diminishing a small degree of pain, or itching, in any part of the body.. As therefore the convulsive motions of coughing, sneezing and the hiccup, are undoubtedly owing to an uneasy sensation affecting the mind, may we not justly conclude, that the gentler *stimulus* of the blood, in the vessels of the lungs, becomes, through the intervention of the mind or sentient principle, the

* How a stronger sensation should destroy, or render the mind insensible of a weaker one, is a question attended with some difficulty ; concerning which see below Sect. xi. answer to objection 2.

the cause of the less violent motions of the inspiratory muscles?

6. THIS however will still further appear, from considering the *phenomena* of respiration in some morbid cases, and in animals placed in a receiver partly exhausted of air.

α IN acute diseases, where the head is much affected, a remarkable alteration often happens in the breathing: expiration indeed succeeds inspiration in the usual way; but sometimes, after expiration is finished, there is a long pause before a new inspiration is begun. In a patient, whose brain was affected from an *ischuria*, I observed this interval between the end of one expiration, and the beginning of a subsequent inspiration, to be many times from seven to ten seconds: but in a young woman, who died apoplectic, inspiration sometimes did not succeed the expiration, till after I had counted 20, 30, 40, or even more beats of my pulse, which did not vibrate above 75 times in a minute. This *phenomenon*, which is easily explained, upon
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the principles we have laid down, is altogether inconsistent with every mechanical account of respiration that has hitherto appeared, or indeed with any, we presume, which may possibly be devised hereafter.

IN these cases, the brain, and common *sensorium*, being greatly affected, the mind or sentient principle must have been much less sensible, than it usually is, of any impression, irritation or *stimulus* affecting the nerves. Hence, after expiration, which, from the resiliency of the cartilages of the ribs, &c. naturally, and without the intervention of the mind, succeeds inspiration, a long pause intervenes before a new inspiration comes on ; because the mind is not roused to exert her influence, till the uneasiness and sense of suffocation in the breast becomes so considerable, as to awake her, as it were, out of a profound sleep. Let any one, after expiration is finished, keep his *thorax* in that state for half a minute or more, and he will feel, before that time is elapsed, such an uneasiness in his breast, as will beget in him the strongest desire
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of dilating the lungs, and taking in fresh air.

It is plain, that, after such a stop, if *Boerhaave's* theory were true, inspiration never could succeed, because it must necessarily occasion a much greater obstruction to the motion of the blood through the lungs, than can ever happen at the end of inspiration, and consequently render the inspiratory muscles altogether unable to overcome their antagonists, and dilate the *thorax*.—If respiration were owing to the alternate compression of the phrenic nerves, would not these nerves, on account of the blood accumulated in the vessels of the lungs, be more compressed 20 or 30 seconds after expiration, than just when it was finished, and consequently be rendered then more incapable to actuate the inspiratory muscles?

β BUT the truth of what we have been contending for, will still further appear from the following history. A child of five years of age, having, at 7 o'clock in the evening, swallowed, by mistake, about a dram and a half of liquid *laudanum*, soon became

became merry, and laughed, then delirious, and in half an hour was seized with a sleepiness and *stupor*; at 10 her breathing was high, with a snoring noise, her pulse full and equal, though slow; she could not be fully awaked, but looked up a little, and seemed to be sensible of pain, when severely pinched: about 11 her face became pale, her eyes fixed and glazed, and her breathing would often gradually decrease, and at last stop, for near a minute; then it began again with a very deep inspiration and sighing. At first when the breathing began to be thus interrupted, the intervals were shorter, but became gradually longer till the patient died. While the motions of respiration were decreasing, the pulse was smaller; and when they were altogether stopt, it was very weak and slow; but equable and without intermissions: when respiration began to be renewed, the pulse recovered its strength, and became less slow.

THE interrupted breathing is easily accounted for, from the *stupor* and insensibility which *opium* never fails to occasion when
taken

taken in too great quantity ; and the intervals becoming gradually longer, could be only owing to the senses being more and more lock'd up by the further action of the *laudanum*, till at last, the mind becoming altogether insensible of the *stimulus* or sense of suffocation in the lungs, a final stop ensued. Add to this, that from the remarkable weakness and slowness of the pulse while respiration was suspended, it is evident that its recommencement could not be owing to any mere mechanical cause ; for the secretion of spirits, and every function of the body depending on the general circulation of the fluids, must have been more languid immediately before the renewal of respiration, than when it began to cease. It would be in vain to pretend to account for the *phenomenon* now mentioned from any compression of nerves, or alternate oscillations of a highly elastic fluid in the fibres of the inspiratory muscles ; for when the heart itself was sinking, and all motion in the body was ready to cease, every mechanical power that can possibly be imagined to excite respiration, must have been less able to renew

this motion, than it was a little before to have continued it.—Lastly, since the pulse was at all times slow, and in the intervals of respiration, not only weaker than usual, but also more remarkably slow, it appears that the heart was in some measure rendered less obedient to the *stimulus* usually affecting it *. Nor is this surprising; since, from the dissections of living animals, we know, that a large dose of *opium* almost entirely suspends the peristaltic motion of the stomach and intestines †. The heart seems to be endued with a much greater degree of sensibility than the lungs; and this perhaps may be the reason, why its motion was less remarkably disturbed by the *stupor* occasioned by the *laudanum*, than that of respiration, which, besides, is performed by muscles, whose fibres or membranes have no *stimulus* immediately applied to them.

γ IN the *Edinburgh Medical Essays*, vol. V. art. 55. we are told, that, after blowing into the lungs of a man, who had been dead to all appearance for above half an hour, the

* See below, Sect. xiv. No 24, & 25.

† *Kaau* impet. faciens, No 434, & 435.

the *thorax*, which was by this means elevated a little, continued alternately to rise and fall, gradually acquiring greater degrees of motion, till at last respiration came to be as fully performed as in healthful people.

Could this be owing to any mere mechanical powers in the body? No, surely. A machine adjusted according to the most exquisite rules of art, tho' it might for some time have preserved the motion communicated to it, could never of itself have generated a greater motion! In order therefore to account for the renewal of respiration in this case, we must have recourse to the energy of the SENTIENT PRINCIPLE, exerted, here, in consequence of the motion imparted to the fluids in the lungs, by their first inflation.

♢ THOUGHTFUL melancholy people, whose minds are greatly taken up with, and strongly attached to certain objects, being hence less affected by the *stimulus* or slight uneasiness which begins to be felt in the lungs, after expiration is ended, usually perform respiration more slowly, and after longer intervals, than those who are in perfect

fect health ; by which means, the blood passing less freely through the pulmonary vessels, and being accumulated in them, a sense of weight and suffocation arises, which more powerfully affects the mind, obliging them, often, to draw in a more than ordinary quantity of air, and occasioning what is usually called a deep sigh.

By what mechanism can it be, that in the half-exhausted receiver of an air-pump, animals breathe quicker and higher than in the open air ? Certainly, upon *Boerhaave's* principles, the motions of respiration ought not to be redoubled in this case, since the blood flows with greater difficulty through the lungs. And if, according to *Swammerdam* and *Pitcairn*, the alternate motions of the *thorax* were owing to the inspiratory muscles having no antagonists, how could this be altered by the air's being rendered lighter, or in what possible way could this or the stagnation of the blood in the lungs, make these muscles repeat their contractions more strongly and frequently ? But it is evident, upon the theory we have endeavoured to establish, that in proportion as
the

the air in the receiver is exhausted, and respiration becomes more difficult, the mind must increase its efforts, in order to dilate the lungs more fully, and to get rid, if possible, of that anxiety, or sense of suffocation, which ever accompanies the stagnation of the blood in the pulmonary vessels, or its difficult passage through them.

¿ LASTLY, upon what *hypothesis*, founded wholly in the received properties of bodies and the laws of motion, can it be shewn, that the frequency and fulness, slowness and smallness of respiration should, in healthy people, be constantly in proportion to the heat and cold, rarity and density of the air?

7. RESPIRATION differs from most of the other spontaneous motions, in being subject to the power of the will: thus we can at pleasure accelerate, retard, or put an entire stop, for a considerable time, to the motions of the intercostal muscles and diaphragm: nor is this power of the will over these muscles owing (as *Boerhaave* thought

thought*) to the mind's preventing their alternate contraction, by means of the stronger voluntary muscles, which are employed in laborious respiration; for any one, by trying the experiment, may soon satisfy himself, that, without the assistance of any other muscle, he can, when he pleases, contract the diaphragm with different degrees of force, or hinder its motion altogether.—But though respiration thus differs from the proper involuntary motions, yet it does not perfectly agree with those that are voluntary, since it is regularly performed in time of sleep, and when we are awake, although we be not conscious of it.

α THE motions of the intercostal muscles and diaphragm are not, like those of the heart and intestines, independent on the will, because the *stimulus* exciting their action is applied to a distant part, and not to the organs moved; and while such *stimulus* is gentle, and the part affected by it not very sensible, as is plainly the case of the lungs,

lungs, the contraction of the muscles that is wont naturally to follow it, may be prevented by the interposition of the will; but if the *stimulus* and uneasy sensation be greatly increased, the usual motions ensue, in spite of any determination of the will to the contrary. Thus, when the membrane of the *trachea* is only slightly irritated, we can restrain coughing; but when it is more strongly affected, all endeavours to hinder it are in vain.—When an ordinary *stimulus* to go to stool or to make urine urges us, though the diaphragm and abdominal muscles be, as it were, spontaneously contracted, yet we can restrain their motions if we please; but in a violent *tenesmus* or stranguery, they are convulsively contracted, notwithstanding any effort of the will to the contrary.—In like manner, the *stimulus* exciting the usual contraction of the inspiratory muscles, after expiration is finished, is so gentle, that we can at pleasure prevent its taking place; but in severe asthmatic fits, where the uneasy sensation is vastly increased, the will begins to lose its power of restraining the motion of these muscles;

pay,

nay, even some of the voluntary muscles, at this time, are forced into action for their assistance: and if, in such cases, the will can at all stop the motions of the inspiratory muscles, it is not so much by its immediate power over them, as by means of the stronger muscles employed in voluntary respiration.

It must indeed be acknowledged, that although the contraction of the orbicular muscle of the *uvula* be not owing to any *stimulus* immediately applied to it, but to the irritation of a distant part, yet it is altogether independent on the will; and in this differs from respiration, and from the motion of the muscles employed in coughing, and in voiding the urine and *feces*. Perhaps the reason of this difference may be, that the action of light upon the very sensible *retina* affects the mind so strongly, that we cannot, by any power of the will, prevent the contraction of the pupil: further, it is not impossible that the will, merely through disuse, may have lost its power of restraining the motions of the muscular

muscular fibres of the *uvea*, even when the *stimulus* is ever so gentle *.

BUT whatever may be the efficient cause, which thus subjects respiration to the government of the will; the final cause of this difference between it and the other vital motions is pretty evident: for were it not that the motions of the muscles employed in respiration may be varied at pleasure, we should not only be unable to evacuate the urine and *fæces*, but must have been deprived of the happiness and advantage of communicating our thoughts to one another in the way of speech.

§ IF it shall be objected that the motion of respiration cannot be owing to the mind or sentient principle, because it obtains at all times, and is kept up when we are asleep and not conscious of it, equally as when we are awake and attentive; it may be a sufficient answer, to observe, that a variety of actions are performed by the influence of the mind, without our adverting to them in the least. To give but one in-

F f

stance :

* See above Sect. 1. N^o 18.

stance: The eye-lids never cease, after short intervals, to move, whether we be sensible of this or not, nay frequently, as when any thing threatens the eye or touches the *cornea*, they move whether we will or no; and yet these motions are undoubtedly owing to the mind. Why, therefore, may not respiration be carried on much in the same manner, without our attending to it; especially since we have shewn that the difficult passage of the blood through the lungs, and the uneasy sensation thence arising, must at all times influence the mind to continue this action?

IN time of sleep, do we not often swallow the spittle, talk, move our limbs, and entirely change the posture of our bodies? Nay, some persons get out of bed, and traverse about from one room to another. Here, then, are actions certainly performed in sleep, which, nevertheless, must necessarily be ascribed to the action of the mind.—Further, in cases where breathing is difficult, when the patients are no ways conscious of it, nay even in time of sleep, respiration seems to be performed, partly
by

by the assistance of other muscles besides the proper inspiratory ones, *i. e.* by muscles which commonly are not employed except in voluntary motion, and whose action, therefore, in such extraordinary cases, must be attributed to the mind alone. On what pretence of reason, therefore, can it be urged, that the motions of the diaphragm and intercostal muscles, since they continue to be performed while we are asleep, are in no ways owing to the mind?—If, while a child is asleep, and breathing softly, a thick cloth be laid over its face; it will immediately begin to breathe deeper or quicker, and will go on to respire in this manner, till, the cloth being removed, the cool air is admitted into the lungs. This, undoubtedly, must arise from the uneasiness which the mind feels from the difficult passage of the blood through the lungs, and the want of proper air; in order to get rid of which inconveniencies, it moves the *thorax* with uncommon force and frequency, whence a greater quantity of air is inspired, and the lungs are more widely dilated.—In an *asthma*, does not the sense of suffocation

tion excite the mind to redouble the motions of the inspiratory muscles, and are we not sensible of this when awake? In sleep, when we are less conscious of this uneasiness, does not the mind persevere in exerting its influence in the same manner upon these muscles? A strong argument this, that the mind, as a sentient principle, is often affected by what passes in the body, and is, in consequence of this, excited into action, when, in the mean time, we do not advert to any such thing.

S E C T. IX.

Of the beginning of respiration in animals.

AS it would be altogether unnecessary to prove, that the *fœtus* cannot possibly perform the action of respiration, when it is in the womb, and inclosed in its membranes; I shall take it for granted that animals do not begin to breathe, till the external air has access to them, at the time of birth; though I find, not indeed
without

without surprize, some of the moderns going into the contrary opinion *.

IT may, perhaps, be thought presumptuous in me to undertake the solution of a problem, which some of the greatest Physiologists have attempted in vain: however, I cannot help thinking it full as easy to account for the first commencement of respiration, as for its continuance when once begun; and that both are owing to the same cause, namely, to an uneasy sensation in the lungs.

OUR bodies, framed, as they are, with the most exquisite skill, would soon perish if deprived of aliment and air. The former of these, must be supplied at short intervals, but the latter can hardly be wanted for a moment. The *fœtus*, while in the womb, stands not in need either of the one or the other; the mother's juices, transmitted to it through the vessels of the *placenta*, supplying the want of aliment; and the peculiar circumstances of its heart making the alternate motion of respiration, which

* *Mazini opera*, tom. 3.

which is requisite for carrying on the circulation of the blood in animals after birth, unnecessary here ; while the mother's fluids, having sustained the action of the air in her lungs, are duly fitted for all the purposes of the *fœtus*, without any respiration of its own. The necessity, therefore, of air and aliment commences with our birth ; and as we are excited to take in meat and drink by the uneasy sensations of hunger and thirst, which, as faithful monitors, never fail to warn us when these are wanted, but immediately cease upon the appetite's being satisfied ; so, to prevent our being in danger of perishing through the want of fresh air, there arises, unless the action of breathing be continually repeated, and new supplies of fresh air thus brought into the lungs, an uneasy sensation, which may not improperly be termed the APPETITE of breathing.

IF then an appetite for fresh air be as natural to animals after birth, as a desire for aliment ; and if no one ever yet thought of accounting either for the sensations of hunger and thirst, or for the taking of
food

food consequent upon them, merely from the mechanical construction of the stomach, gullet and *fauces*, without having recourse to the mind; is it not highly unreasonable and unphilosophical to attempt to explain the action of respiration from principles purely mechanical, and to deny the perception and operation of a sentient active principle to be the cause which at first begins, and ever after continues it? This analogy is too strong not to strike every unprejudiced mind!

BUT it may be here asked, in the way of objection, if the *fœtus*, during its confinement in the womb, has an inclination to breathe, why is not the *liquor amnii*, like the air after birth, received into its lungs, and expelled alternately*: The answer to which is,

I. THAT

* Dr *Martine* has proposed it as a problem; why the *fœtus* in time of gestation never dilates its *thorax*, nor at any time before birth performs, however slowly, the motions of inspiration and expiration successively. Medical Essays, vol. 1. art. xii.

I. THAT had the *fœtus in utero* ever so strong a desire to perform the action of respiration, it could not admit the *liquor amnii* into its lungs; partly on account of water being a fluid altogether improper for the purposes of respiration, but more especially because, whenever it so much as touches the top of the *larynx*, the *glottis* is so constricted, by the convulsive contraction of its muscles, that scarcely can even one drop pass into the lungs. This appears evidently from its being observed, that those animals, which have been immersed and kept under water, do not admit any of this fluid at all into their lungs, much less such a portion of it as might properly be esteemed the cause of their death*. If, therefore, a small quantity of water has at any time been found in the lungs of drowned animals, we are not to suppose it made its way thither while they were alive, but only after their death, when, the muscles of the *glottis* losing their

* Histoire academie des sciences 1719, edit, 8vo. p. 32. and 1725, p. 16.

their power of contraction and becoming flaccid, the sides of this passage recede from each other.

THE different cravings or appetites have severally their corresponding objects: fresh air, on account of its cooling quality, and because it equably and gently dilates the lungs, and thus promotes the circulation of the blood through their vessels, is as well adapted to satisfy the appetite of breathing, as thin cooling drink is to quench thirst; whereas water would be altogether as improper for the purposes of respiration, as dry bread for diluting our fluids, or satisfying the cravings of a thirsty animal. Hence as food has the highest relish to a hungry person, so, to one half suffocated for want of air, nothing is more refreshing or more greedily taken in than this fluid.

SINCE, therefore, it appears from what has been said, that water is wholly unfit for satisfying the appetite of breathing, and that animals which have been long accustomed to respiration, never so much as attempt, when under water, to draw it into their lungs; it

follows, that the *fœtus in utero*, even supposing (what seems not however to be the case) it had the same appetite of breathing with animals after birth, could not receive the liquor of the *amnios* into its lungs, and expel it thence alternately. Thus we see how easy a solution Dr *Martine's* problem admits of; and that, for this purpose, it is quite unnecessary to have recourse to any imaginary compression of the phrenic nerves. But,

2. It seems probable that either the appetite of breathing does not take place in *fœtuses* till birth, or that it becomes then much stronger; for,

α THE uneasy situation of the *fœtus*, when the birth is just at hand, and its various motions and struggles in consequence of this uneasiness, must remarkably quicken the circulation of the blood through its vessels; whence the lungs will not only receive a larger share of fluids in a given time than formerly, but the blood passing in greater quantity than usual from the left ventricle of the heart into the *aorta*, and making
therefore

therefore a stronger resistance to the passage of this fluid through the *ductus arteriosus*, it must now be more copiously determined into the pulmonary artery, from whose beginning this duct arises. But if the blood be thus pushed in greater streams into the vessels of the lungs at, and even somewhat earlier than the time of birth, must there not hence ensue a greater degree of heat, and fulness, a more active *stimulus* and uneasiness in these vessels; or, in other words, must not the appetite of breathing be hence necessarily increased *? After birth, when the *fœtus* remains for some time inclosed in its membranes before it is allowed to breathe, this increased motion of its blood may well be supposed to be much abated; however the cold, which it is now much more exposed to than formerly, by contracting the placentary and cutaneous vessels, must accelerate the return of their blood to the right ventricle

* Altho' immediately before birth the *fœtus* may be so pressed upon and confined by the parts surrounding it, as to prevent its making any considerable motions, yet the pain as well as the strong alternate pressure which it suffers, cannot fail, at that time, to quicken the circulation of its blood.

ventricle of the heart, and, by this means, increase the force of the circulation in the interior parts of the body.

CHILDREN, which have been cut out of their mother's womb, often remain a considerable time without attempting to breathe, because there is no such increase of the blood's motion thro' their lungs, as happens in children which are brought forth in the natural way, and which, therefore, must have a greater inclination to inspire. It is to be observed, however, that, in some cases, weakness, and consequently a very languid circulation through the lungs, is the cause why children delivered in the usual manner, as well as those who are cut out of the *uterus*, do not begin to breathe for a considerable time, after they are exposed to the air.

It has been observed, that when the *uterus* of a living bitch is opened, the puppies inclosed in their membranes remain quiet for some time; but, about the time of the mother's death, they begin to stir about and struggle, as if affected by some very uneasy sensation; and that if their membranes be
laid

laid open at this time, or a little after, so that the air shall be admitted to them, they immediately begin to breathe, and seem to be relieved from what before oppressed them; but if this is not done, they quickly begin to languish and at last die*. Does not this argue that a necessity of respiration, and a desire, stronger at least than before, of dilating the *thorax* for the admission of air, commences on the part of the *fœtus*, immediately after its intercourse with the mother is cut off by the birth?

γ As the water surrounding the *fœtus* would certainly hinder its making any efforts to inspire, though it were supposed ever so desirous of doing it, so the air, the proper *medium* for respiration, being applied after birth to the face, mouth and nostrils of the animal, may put it upon essaying a new action, which, by reason of the peculiar sensation in its lungs, it cannot but be extremely anxious to perform. We may observe that a new-born child rarely attempts

to

* “*Fœtum cum suis involucris eximo, et exteriori effracto in-
“volucro per interius valde pellucidum ostendo qui fœtus respi-
“rare conetur, quamque pulchre interiori quoque fracto ærem
“ducat.” Vesalii anatom. lib. 7. c. 19.*

to suck except something be applied to its mouth; and, perhaps, in the same manner the appetite of breathing itself may be increased in a *fœtus* by the presence of a fluid fitly answering its demands.—The chick, after it is become large and strong, is observed to gape when the shell is opened; and does not this indicate a desire of breathing? this opening of the mouth cannot be in order to take in the liquor of the *amnios* since the chick is nourished, not by the mouth, but by the umbilical vessels alone *.

UPON the whole, altho' it is not altogether improbable that the *fœtus*, during its stay in the womb, may, especially towards the end of gestation, from the difficult passage of the blood through its compressed lungs, have a desire to breathe, provided it could enjoy the benefit of air, yet it scarcely can be doubted that this appetite of breathing must be greatly increased at birth. Nor is breathing the only action performed by a child newly born, which before it was a stranger to; sucking being equally new to it.

* See Edinburgh Medical Essays, vol. 2. art. 10.

it as breathing *. The former has been generally referred to instinct, and so perhaps may the latter: but as I would decline, as much as possible, the use of words, whose meaning may be obscure or indeterminate; I chuse rather to say, that sucking and breathing are owing to particular sensations in the body, determining the mind or sentient principle to put certain muscles or organs in motion.

HAVING thus accounted for the beginning of respiration in animals, we shall, in a few words, shew the weakness of what has been advanced on this head by some of the most considerable writers in Physiology.

OUR celebrated countryman Dr *Pitcairn* derives the first inspiration in new-born animals, from the air rushing, by the *glottis*, into the cavity of the *thorax* at birth, as it were into a *vacuum*, and thus enabling the
intercostal

* That the *fœtus in utero* does not swallow the *liquor amnii*, has been so clearly demonstrated by my learned Collegue Dr Alexander Monro senior, that I think it one of the few points in Physiology which ought for the future to pass undisputed. See *Edinburgh Medical Essays*, vol. 2. art. 9.

intercostal muscles to raise the ribs *. But as the lungs, before birth, fill the *thorax*, there can be no *vacuum* into which the air may rush: for, if there were, the *liquor amnii* must have been forced into it, while the *fœtus* was in the womb; and in dead-born *fœtuses*, the air ought to rush into the lungs and expand them; both which circumstances are contradicted by experience. The Doctor adds, *Irrumpit, inquam, aer vi elateris et gravitatis, non autem dilatati prius pectoris, compulsus* †; whence it is evident he was quite unacquainted with the true manner in which inspiration is performed: for it is owing, as has been shewn above, to the enlargement of the cavity of the breast, made by the contraction of the intercostal muscles and diaphragm. Besides, since the *thorax* is in a state of full expiration in all dead animals, it evidently appears that the
 air

* Differt. de caus. qua sanguis fluit per pulmon. sect. 14.
 P. 53.

† Differt. de caus. qua sang. fluit per pulmon. sect. 15.
 P. 54.

air cannot, by its gravity, &c. dilate the lungs; but that, in order to the first inspiration, the diaphragm and intercostal muscles, by their contraction, must enlarge the cavity of the chest.

THE great *Boerhaave*, after *Thruston* and *Borelli*, ascribes the beginning of respiration to the *fœtus* moving all its muscles violently in the time of birth, and, among the rest, the intercostals and diaphragm*. But this account is by no means satisfactory; since *Vesalius* and Mr *Boyle* have observed, that puppies cut out of their mother's womb begin to gape and breathe as soon as they are exposed to the open air†. And when infants, which seemed to be dead-born, have begun soon after to breathe, we are not, with the illustrious *Senac*, to ascribe this to the action of any secret *ressort*, or undiscovered piece of mechanism, bringing the muscles of inspiration at this time into play‡; but to the energy of the sentient

H h principle,

* Institut. Med. § 691.

† *Vesal.* Anatom. lib. vii. cap. 19. & *Boyle's* exp. physic. mechan. p. 41.

‡ *Traité du coeur*, lib. 3. cap. 8. Sect. vi.

principle, which, as soon as the heart begins to vibrate, is roused by a disagreeable feeling in the lungs, to dilate the *thorax* and take in air. The cause, therefore, of the first inspiration in this case, is evidently the same as of its recommencement after a *syncope*, namely, the blood pushed by the heart, upon its recovering motion, into the pulmonary vessels, and there acting as a *stimulus*.

THE learned M. *de Haller* chuses to deduce the beginning of respiration, from the endeavours of the *fœtus* to cry, upon account of its uneasy situation and the pain it suffers in the time of birth *. But, if the commencement of breathing were owing to no other cause than this, why should not this action cease soon after the child is delivered, when it is free from pain and gives over crying? Or why should it begin in *Vesalius* and *Boyle's* experiments now mentioned, where the usual causes exciting the animal to cry were wanting? And why

* Not. *a* in Boerhaave Institut. Med. § 691. & prim. lin. Physiolog.

why should the *fœtus* shew such marks of anxiety when inclosed in its membranes, and be quickly at ease, upon its having access to the air and being allowed to breathe?

BUT what is crying in infants? Why, no more than an irregular kind of breathing, which affects the expiration chiefly, and is owing to some painful sensation; for, hence the air being forcibly expelled through the *glottis*, which is constricted now more than usually, produces that noise called CRYING. To tell us therefore, that the beginning of respiration in animals is owing to their attempting to cry, is, in other words, to say, that it depends upon a painful sensation, which, in animals accustomed to breathe, prevents the muscles of respiration from being moved in a regular and natural way. But, as the action of these muscles is performed in a more regular and equable manner as soon as the cause of crying ceases, it seems more reasonable to believe that the first inspiration is owing to the same cause as the second, third, and every succeeding one, namely, to

a particular sensation in the lungs affecting all new-born animals; while the pain, which occasions crying, is merely accidental, and seems not to give rise to respiration, when it does happen; though, after it is once begun, it is the cause of its being performed after an irregular and interrupted manner.

ANIMALS, when drowned, or suffocated with bad air, are many times brought to life again by friction, agitation, or by blowing air into their intestines or lungs; all which expedients, as they communicate motion to the blood stagnating in the great veins adjoining to the heart, tend to renew the contractions of this organ, and consequently the circulation of the blood through the vessels of the lungs, to which alone the recommencement of breathing is owing, and not to any attempt to cry or howl, which, in these cases, is seldom observed.

FURTHER, in bats, hedge-hogs and other animals which ly in a death-like state during the winter's cold, and without any alternate motion of their *thorax*, can the recommencement of breathing, in the spring season,

season, be ascribed to any painful sensation exciting them to cry? No, surely. But the returning heat of the sun agitating their fluids, and communicating a new motion to their heart, the blood is pushed, as is usual in living animals, into the pulmonary vessels, where, chiefly on account of its difficult passage, it excites a peculiar sensation, which rouses the soul or sentient principle, as it were, from its state of indolence and inactivity, to contract the inspiratory muscles, and thus perform the action of respiration.

UPON the whole, I think it evident that the beginning of respiration in new-born animals, or the recommencement of it in those in which it has been for a long time interrupted, cannot with any sort of justice or propriety be deduced from an inclination to cry*; but is owing to a peculiar sensation

* The learned M. de Haller, in his *Elementa Physiologiæ*, tom. iii. p. 318. (published since the first Edition of this Essay,) not only ascribes the beginning of respiration in animals to their endeavouring to cry at the time of their birth, but chiefly to their having been accustomed, while in the *uterus*, to swallow

tion in the lungs, which as it at first gave rise to this action, so it is the cause of its being

swallow the liquor of the *amnios*; whence they are no sooner exposed to the air, than they draw in this fluid, with which they are now surrounded.

But supposing, what is no ways probable, that the *fœtus*, while in the womb, had been in use to swallow the liquor contained in the *amnios*, it will not follow that it should inspire, or draw the air into its lungs, as soon as it is born; for the action of inspiration is altogether different from that of deglutition, and is performed by different instruments and organs.—If the *fœtus* had been accustomed to swallow before birth, it might indeed, immediately after it, be apt to move the organs of deglutition, and swallow its own *saliva*; but how should this action occasion inspiration?—The motion of the *larynx* and *fauces* in deglutition, cannot have the smallest influence in producing a contraction of the diaphragm or intercostal muscles: And we do not find that hunger, or a strong desire to swallow either liquid or solid food, ever increases that inclination which animals have to perform the action of inspiration; on the contrary, after we have fasted long, we breathe seldom more than after a full meal. In like manner, when, in consequence of being half suffocated by breathing in too confined an air, we have a much greater desire than usual to inspire, we do not find that our sense of hunger, or inclination to swallow is thereby increased. And indeed, there is nothing more certain than that a desire to swallow is as different from, and has as little connexion with an inclination to breathe, as a sense of hunger in the stomach has with a sense of suffocation in the lungs.

being ever after continued. And if we are so formed, that we feel a craving appetite, as often as our bodies require a new supply of food, and a different sensation when our fluids need to be diluted with drink, can it be thought strange that an appetite should be given us for air, the want of which becomes much sooner fatal?

A Solution of HARVEY'S Problem.

Qui fit, ut fœtus in lucem editus, ac membranis integris opertus, et etiamnum in aqua sua, manens, per aliquot horas, citra suffocationis

In animals, which have been drowned, or suffocated by bad air, respiration is restored by friction of the *abdomen*, blowing into the *anus*, or by any other means that can renew the motion of the blood through the heart and lungs; In this case, therefore, the recommencement of breathing cannot be owing to a sense of hunger, or a desire to swallow.

Further, if, as I have endeavoured to prove, and as M. *de Haller* himself allows, the continuance of respiration in animals be owing to an anxiety or disagreeable sensation in the lungs arising from the slow passage of the blood through their vessels; is it not more reasonable to ascribe the beginning of respiration in new-born animals to such an uneasy feeling, than to an inclination to swallow?

*nis periculum, superstes sit: idem tamen secundis exutus, si semel aërem intra pulmones attraxerit, postea ne momentum quidem temporis absque eo durare possit, sed confestim moriatur *?*

THIS problem, which was first proposed by the great Dr Harvey, appears to be of so very easy solution, that it is not a little surprising, that many Physiological writers should have attempted it in vain.

THE *fœtus* lives in the womb without respiration, because the greatest part of the blood, by means of the *foramen ovale* and *ductus arteriosus*, is conveyed from the right *sinus venosus* and ventricle of the heart into the left ventricle and *aorta*, without passing through the lungs; and because its fluids, being derived from the mother's blood which has sustained the action of the air in her lungs, must be equally fit for its nourishment and support, as for her's.—When the *fœtus*, after being separated from its mother, remains involved in its secundines, it lives for a considerable time without breathing;

* Harvey de generat. animal. cap. de partu, p. 501.

ing; because the circulation of the blood continuing to be carried on in the same manner as when it was in the womb, only a small proportion of it passes through the lungs.

AFTER birth, when the *fœtus* has once been accustomed to breathe, it soon dies, if respiration is discontinued*; because the blood, which formerly went by the *foramen ovale* and *ductus arteriosus*, passes now thro' the vessels of the inflated lungs: and although we cannot suppose these passages to be instantly shut after breathing begins, yet as the vesicles of the lungs, after having been once inflated, never collapse so far as to occupy as little space 'as before, their vessels must go on to receive a greater quantity of blood than before birth, and consequently to transmit this fluid in greater abundance to the left *sinus venosus*; by which

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* M. de Haller * has well observed that notwithstanding Harvey's words may seem to insinuate that a *fœtus* which has once breathed, *instantly* dies after this action is interrupted, yet *fœtuses* which have breathed only for a short time, can live several minutes without respiration.

* Element. Physiolog. torn. iii.

means the passage of the blood into this *sinus*, by the *foramen ovale*, will, in a great measure, be prevented; at the same time, by the inflation of the lungs, the pulmonary artery will be raised, and the situation of the *ductus arteriosus* so changed, as to render the passage of the blood through it less favourable. Further, after birth, when the umbilical arteries are tied, the blood passing through the *ductus arteriosus* into the *aorta* will meet with greater resistance than formerly; since the fluids pushed into this artery by the two ventricles of the heart, will find a less ready passage, as a considerable part of the vessels through which they used to flow are thus obstructed.

HENCE if respiration be once begun, though performed but for a short time, the blood, notwithstanding its being afterwards restrained, will continue to take chiefly the *route* of the lungs, through whose vessels, however, it cannot pass near so fast as it is thrown into them from the right ventricle of the heart; whence it follows, that an animal, having been once accustomed to breathe, and after this happening to be deprived

prived of air, must be soon suffocated by an accumulation of blood in the pulmonary vessels *.

SOME

* As there have been some who doubted of the alternate motion of the lungs in respiration, being necessary to carry on the circulation of the blood through their vessels, I shall here mention a few experiments, which seem to put this matter out of doubt.

1. When the lungs are collapsed, *i. e.* in a state of expiration, as is the case of all dead animals, any fluid injected into the pulmonary artery, passes with difficulty to the left ventricle of the heart.

2. When the lungs are inflated with air, an injected liquor flows through their vessels more easily and in greater quantity.

3. When the lungs are agitated with an alternate motion, something like natural respiration, water or any other thin fluid passes still more freely through them, and penetrates into their most subtle vessels*.

4. If respiration be restrained for any considerable time, one's face becomes of a purple colour, and its veins are much distended with blood; which shews that this fluid, on account of its difficult passage through the lungs, is accumulated in the trunks of the *cava* and right *sinus venosus*.

5. The necessity of the alternate motion of respiration in order to the free transmission of the blood through the pulmonary vessels, is still more evidently demonstrated by the following experiment of Dr *Musgrave*: A dog whose *trachea* was cut, just below the *pomum adami*, and close stoppt with a cork, after a few violent struggles, died in two minutes; and, upon opening the *thorax*, the pulmonary artery, right ventricle and

* Vid. *Kaau* perspirat. Hippocrat. dicta, sect. 160, 161, 162, & 170.

SOME may perhaps think the sudden death of animals deprived of the benefit of respiration,

and auricle of the heart, together with the great trunks of the *cava*, were distended with blood to an excessive degree; while the pulmonary veins, left auricle and ventricle of the heart, were almost quite empty, not containing more than a spoonful of blood*.

It may be thought perhaps that the force of this experiment is weakened by one of Dr *Hook's*, who having cut away the ribs, diaphragm and *pericardium* of a dog, and pricked the outer coat of the lungs with a penknife, preserved him alive, by keeping his lungs fully distended with a continued blast of air, which he made to pass through them by means of a pair of double bellows †. But as the blood flows much more freely through the pulmonary vessels when the lungs are inflated, than when they are collapsed, it is by no means surprising, that in this dog, which had lost a great deal of blood during a former experiment, the inflated lungs should afford an easy enough passage to the small quantity of this fluid that would be thrown into their vessels by the contraction of the right ventricle of the heart; especially if we consider, that the constant stream of air must necessarily, while it was passing through the lungs, and escaping by the small wounds made in their external surface, have communicated a considerable oscillatory motion to all their vesicles and vessels, whence the motion of the blood through them would be greatly promoted. And that a very small agitation of the lungs may be sufficient to keep up the circulation through their vessels, and preserve life, plainly appears from the faintings which hysterical people are sometimes subject to. In these faintings, which I have seen

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* Philosophical Transact. abridged, vol. 3. p. 67.

† Ibid. p. 66.

respiration, is owing rather to the want of something in the air which supports the vital flame. But without entering into a discussion of those arguments which may be brought for and against this opinion, I shall only observe, that since a *fœtus* can live a considerable time without respiration, when separated from its mother and involved in its secundines, its dying sooner for want of air, after it has once breathed, cannot be owing solely to the defect of any thing which this fluid might communicate to the blood in the lungs, but must be deduced from the change made in the pulmonary vessels by respiration, as has been above

last from 5 to near 15 minutes, the pulse beats a very little slower and feebler than before, but with its usual regularity; while in the mean time there is no motion of the *thorax* observable to the eye; however, by holding a lighted candle near the mouth, one can easily discover that they breathe, though it be very weakly and slowly. Further, in Dr *Hook*'s experiment, the passage of the blood through the pulmonary vessels must have been much freer than it is in sound animals, whose lungs are kept in a state of full inspiration, because they are, while in this state, considerably pressed upon by the rarified air endeavouring to inflate them more and more on the one hand, and the sides of the *thorax* resisting this inflation on the other.

bove explained. And this reasoning is confirmed from the observation, that animals, through whose lungs a small share only of the blood circulates, can sustain the want of air much longer than man and the other more perfect animals, in which the whole mass of blood passes thro' the pulmonary vessels: as likewise that new-born animals, which have breathed only for a short time, do not die so soon in the air-pump as others do*.

HAVING thus shewn at large, that the vital and other involuntary motions of animals are all owing to *stimuli* of one kind or other, acting either immediately upon the organs moved, or on some neighbouring part with which they seem to have a peculiar sympathy; it remains that we next inquire, whence this power of *stimuli* over the muscles of animals must be derived?

S E C T.

* Philosophical Transact. abridged, vol. 2. p. 217, & 218.

S E C T. X.

Of the reason why the muscles of animals are excited into contraction by stimuli.

THE muscular fibres of animals are so framed, as to contract whenever a cause proper to excite their action is applied to them, or, in defect of this, always to remain at rest. This cause is either an effort of the will *, or a *stimulus* of some kind or other †: to the former are owing the voluntary motions; and to the latter all such as we call vital and spontaneous.

How or in what manner the will acts upon the voluntary muscles, so as to bring them into contraction, is a question wholly beyond the reach of our faculties; and, indeed, were it otherwise, the answer would be of no great importance, it being sufficient that experience convinces us the will is really possessed of this power. But, in this our endeavour to trace the vital and other

* Sect. 1. N^o 7. above.

† Ibid. N^o 8.

other involuntary motions up to their first source, it seems to be a matter of no small moment, to investigate the cause or causes which enable *stimuli* of various kinds to excite the muscles of living animals into contraction. And here,

I. SOME have contented themselves with ascribing the contractions of muscles consequent upon pricking, tearing, stretching, or otherwise stimulating them, either by the application of solid bodies or acrid fluids, to the elastic power of their fibres*; but without informing us particularly, whether by this they only understood that remarkable power of resiliion belonging to many bodies, and from which they are named elastic, or something different from, or superadded to this. However, these authors would have done well to consider, that an elastic body, of whatever kind it may

* *Bagliv.* opera, 4to, lib. de fibra motrice, cap. 11. p. 335.

& *Differt.* de anat. fibrar. et motu muscul. p. 403.

F. Hoffman. system. med. lib. 1. sect. 1. cap. 3. N^o 17.

& 18.

may be supposed, is no more than a piece of dead inactive matter, without any power of generating motion; and that though it ever recoils with a force proportional to that which bent or wound it up, yet it does this only in consequence of its being acted upon, and not from any proper agency of its own: That the sharpest needle does not produce stronger vibrations in the spring of a watch, than a blunt one acting upon it with equal force; and that spirit of wine, or oil of vitriol, dropt upon the most highly elastic body, disturb not its state of rest, any more than the mildest milk, or oil of almonds. Whereas the contrary of all this is true with respect to the action either of stimulating solid bodies or acrid fluids upon the muscular fibres of animals; whence it follows, that the motions they produce are not to be explained by any elastic powers, which, it may be imagined, these fibres are endued withal.

2. OTHERS, giving scope to a lively imagination, have fancied the animal spirits lodged in the cavities of the muscular

K k fibres,

fibres, to consist of a number of little springs wound up, which, by the application of stimulating bodies, being put into vibratory motions, dilate these fibres, and so render the whole muscle shorter*. Not much different from this is the opinion of the illustrious Dr *Senac*, who tells us, in his accurate Treatise upon the heart †, that this muscle is brought into contraction by the returning venous blood, which dilates its ventricles, and stretches their constituent fibres in such manner, as to excite an oscillation in the animal spirits lodged in them, and consequently to make the muscular substance of the heart swell and become hard.

BUT, waving the objection, that as the nature of the animal or vital spirits, as they are called, is altogether beyond our ken, every account of muscular motion from a *stimulus* which depends on their peculiar energy or manner or action, must therefore be merely hypothetical and precarious at best; may it not well be asked, why, if muscular

* *Lientaud. element. Physiolog. p. 71, 72. & 261.*

† Vol. 1. lib. 2. cap. 8.

muscular contraction from a *stimulus* were owing to the animal spirits excited into an oscillatory motion, should pressing the belly of a muscle with a smooth body produce a weaker oscillation than pricking it with a pin, which is applied with less force, and affects only a very few of its fibres? or why should one and the same irritating cause acting on the fibres of an inflamed muscle, raise a much more violent oscillation of the nervous fluid, than when applied to a muscle in a sound state? — Besides, supposing the animal spirits lodged in the muscular fibres to be ever so elastic, would it not be in vain to go about deducing the motions of muscles consequent upon a *stimulus* from this property, since elastic bodies, as was observed above, never, of themselves, generate motion, but recoil only with a force proportional to that wherewith they are acted upon. If it be pretended, that the animal spirits differ from other elastic bodies, or owe their oscillatory motion to some other cause*, no satisfaction, surely, can arise from such a refuge in ignorance; for these
spirits

* Senac. Traité du coeur, vol. I. p. 452.

spirits must either act entirely as a mechanical power or not: if the affirmative be admitted as true, it must also, at the same time, be confessed, their reaction, like that of other elastic bodies, can never exceed the power acting upon them and putting them in motion: but if their action, instead of being properly mechanical, be ascribed to some unknown active properties, this will be found to be not only a mere *hypothesis*, but such a one as will hereafter be proved utterly irreconcilable with the *phenomena* of muscular contraction from *stimuli*.

3. IT may be thought, that muscular contraction is owing to some kind of explosion, ebullition or effervescence, occasioned by the mixture of the nervous and arterial fluids, or perhaps to the peculiar energy of some very subtile ethereal or electrical matter residing in the nerves; and that as these causes may be brought into action by the power of the will, in order to voluntary motion, so, in the case of involuntary motion, they may be necessarily determined

determined to exert their influence, by the mechanical action of heat, sharp instruments, or other *stimuli* applied to the fibres or nerves of the muscles*.

BUT, without inquiring how far the contraction or intumescence of a muscle may be owing, or not, to any of the causes now mentioned, it will be no difficult matter to shew that they cannot, without the intervention of some other agent, be excited to exert

* Dr *Robinson* has ascribed muscular contraction from heat, punctures, &c. to their exciting a vibrating motion in the *æther* within the nerves and membranes of the muscles; and thinks that the explosion of the electrical vapour brings the muscles into a strong and sudden contraction, by raising a strong vibrating motion in the *æther* lodged in their nerves and membranes. *Animal Economy*, prop. 8. and *Dissertation on Sir Isaac Newton's æther*, Appendix, p. 140. — Dr *Langrish* also is of opinion, that warmth and pricking with a needle renew the contraction of the heart, by putting in motion the ethereal matter of the nerves. *Cronean Lectures*, sect. 127. and 151. — And as of late years there has appeared a fondness in some, to explain almost every hidden operation in nature by electricity, I thought it might not be improper to shew, that the electrical *aura*, even supposing it were the MATERIAL cause of muscular contraction, will not enable us to account for the motions of muscles, whose fibres or membranes are pricked, torn, or otherwise stimulated.

exert themselves by the various *stimuli* which are observed to bring the muscles of animals into contraction: for a fluid lodged in the nerves or muscular fibres, though of a nature fit to produce explosions, effervescences, &c. is by no means sufficient for any of these purposes, unless a cause peculiarly adapted to excite such motions be applied to it. Thus gun-powder produces no explosion without the assistance of fire; nor are electrical *effluvia* excited into action, but by the attrition of certain bodies. Alkalies then only raise a commotion when mixed with acids; and no effervescences or sudden ebullitions can be produced, without the mixture of substances disagreeing in their qualities. Fire applied to a glass globe will not produce electricity, any more than friction will make an alkaline liquor effervesce, or the mixture of an acid set gun-powder in a flame. If therefore muscular motion were owing to any of the causes above mentioned, it might reasonably be expected that it would only follow upon the application of certain kinds of *stimuli* to the muscular fibres: but we know from experience,

ence, that instruments of different metals, provided their sharpness and figure be the same, have an equal power of bringing the muscles of animals into action:— that it makes no odds whether the stimulating substances be electrics *per se*, or non-electrics:— that acrid liquors of quite opposite natures have much the same effect, if their degree of pungency be equal:— that acids, alkalies, neutral salts, heat, pricking, tearing, and in short every kind of irritation, excite muscles of animals into contraction; and that there is no difference in the motions they produce, except what arises from their acting as stronger or weaker *stimuli*, *i. e.* from their irritating the part more or less.

FURTHER, no violent motion is produced by any bodies in nature, however active, unless the peculiar causes necessary to produce such motion be applied to them: but in order to the contraction of a muscle, it is not necessary that the *stimulus* should be applied to its fibres; it is enough that the common membranes covering them are irritated, the same effect being hence produced as from wounding the very fibres of
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the muscle. This is evidently fact, in the case of the heart, stomach, intestines, and bladder ; nay, many times, muscles are excited into action by a *stimulus* affecting a remote part with which they have no immediate connexion, or so much as even a communication by means of nerves, unless it be that general one subsisting between all the parts, as their nerves are derived from the same brain. Thus any thing which affects the interior membrane of the stomach after a disagreeable manner, brings the diaphragm and abdominal muscles into convulsive contractions: the action of light, as a *stimulus*, upon the tender *retina*, is followed by the contraction of the orbicular muscle of the *uvula*, and according to the various impressions made by sounds upon the auditory nerves, the muscles of the internal ear are contracted variously.

LASTLY, As the electrical *effluvia*, excited by the friction of certain bodies, are not emitted by fits and starts, but in a continued equable stream, so neither do the explosions or effervescences produced by the mixture of substances of disagreeing natures exert

exert themselves, like irritated muscles, by alternate efforts. As little will the oscillations of an elastic *æther* (supposing the animal spirits to be of this nature) serve to explain this *phenomenon*, since these must always follow the laws of vibration observed in other elastic bodies, which yet are utterly inconsistent, as we shall have occasion of proving below, with the alternate and vibratory-like contractions of muscular fibres occasioned by irritation. Upon the whole then, we may fairly conclude that the contraction of an irritated muscle cannot be owing to any effervescence, explosion, ethereal oscillation, or electrical energy excited in its fibres or membranes, by the mechanical action of *stimuli* upon them.

4. SEVERAL Physiological writers have supposed some latent power or property in the muscular fibres of animals, to which their motions, in consequence of an irritation, are to be referred *.

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* *Peyer*. *Parerg. anatom.* 7. p. 198.

Haller. not. in *Boerhaave institut. med.* vol. 4. p. 615. & 617.

BUT this opinion seems to be no more than a refuge of ignorance, which nothing, but the despair of any success in their inquiries into this matter, can have driven them into. For, if they here mean some unknown active powers resulting from the peculiar constitution or mechanical structure of a muscular fibre, it may be sufficient reason with us for denying there are any such latent causes, that the assertors of them have hitherto been as unable to vindicate their existence by *phænomena* which cannot be explained without them, as to specify their true nature; besides that it must appear greatly unphilosophical to attribute active powers to that, which however modified

617. Comment. *I. G. H.* in Boerhaave institut. med. vol. 5. p. 101 & 104.

M. de Haller, since the first Edition of this Essay was published, has endeavoured to shew that the motions of irritated Muscles are owing to the glutinous matter connecting those earthy particles of which their fibres are composed; and he supposes irritability to be a particular property of that glutinous substance, in like manner as gravity is a property of matter in general. This notion, however, I have sufficiently refuted in my Physiological Essays, Edit. 2. p. 179.—185. & p. 311. & 312.

dified or arranged, is yet no more than a system of mere matter ; powers I say, which are not only confessedly superior to the utmost efforts of mechanism, but seemingly contrary to all the known properties of matter.

FURTHER, the influence of *stimuli* in exciting even those muscles, to which they are not applied, into contraction, plainly argues such motion not to arise from any hidden power in the muscle being called into action by the mechanical effect or operation of the *stimulus*. Every attempt, therefore, towards explaining the motions of irritated muscles, from properties which their fibres, considered as mechanical instruments, ever so exquisitely framed, or nicely adjusted, can be supposed endued withal, must be vain and fruitless : for as well might we pretend the eye sees objects, and the ear hears sounds, purely by virtue of their being material organs, as imagine the motions of animal fibres from a *stimulus*, to be owing solely to their mechanical structure, or to the peculiar arrangement and disposition of their parts.

5. SOME may, perhaps, be of opinion, that the all-wise AUTHOR of nature hath endued the muscular fibres of animals with certain active powers, far superior to those of common matter, and that to these the motions of irritated muscles are owing. And indeed we cannot but readily acknowledge, that he has animated all the muscles and fibres of animals, with an active sentient PRINCIPLE united to their bodies, and that, to the energy of this PRINCIPLE, are owing, the contractions of stimulated muscles. But if it be imagined that he has given to animal fibres a power of sensation, and of generating motion, without superadding or uniting to them an active PRINCIPLE, as the SUBJECT and CAUSE of these, we presume to say, that a supposition of this kind ought by no means to be admitted ; since, to affirm that matter can, of itself, by any modification of its parts, be rendered capable of sensation, or of generating motion, is not less absurd, than to ascribe to it a power of thinking. Matter, as far as we can judge of it by all its known properties, appears to be
incapable

incapable either of sensation or thought : and the whole *phenomena* of the mere material world evidently shew, that it acts invariably according to certain laws prescribed to it, and without any feeling, inclination or choice of its own ; nor is there any thing more resembling will, self determination, or real active power in the most refined and subtile parts of matter, than in the grossest and most sluggish.

IF then the effects of *stimuli* upon the muscular fibres of animals, cannot be deduced from any property or powers belonging to them, as mere MATERIAL organs, it remains, that they are owing to an active sentient PRINCIPLE animating these fibres. But this will more evidently appear from the following considerations.

I. *Stimuli* applied to the muscles of animals, when laid bare, produce, instead of only one contraction lasting for a considerable time, several contractions and relaxations alternately succeeding each other, which become gradually weaker, and
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are repeated after longer intervals, as the force of the irritating cause is diminished *. Now, these alternate contractions are easily accounted for, if we suppose them to proceed from a sentient PRINCIPLE, which, in order to the getting rid of the pain or uneasy sensation that arises from the irritation of the muscle, determines the influence of the nerves into its fibres more strongly than usual. For, if by one or two contractions the irritating cause be thrown off, and, together with it, the disagreeable sensation removed, the muscle will return to its former state of rest; if otherwise, it will continue for a longer time to be agitated by alternate convulsive motions, which will be more or less forcible, and repeated after shorter or longer intervals, in proportion as the *stimulus* and painful sensation hence ensuing are stronger or weaker. The titillation of a slighter *stimulus* will be so much weakened by the first contraction of the muscle, that some space of time must intervene before it will be able

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* Sect. I. N^o 10, & 11, above.

to produce a second: whereas the smart pain, which follows a strong irritation, affects the sentient principle so powerfully, that no sooner is the muscle relaxed, than a new contraction necessarily succeeds. Thus a gentle irritation of the left orifice of the stomach occasions only a slighter hiccup or convulsive contraction of the diaphragm, which, too, is not repeated till after considerable pauses; while a greater irritation, not only excites stronger convulsions of this muscle, but also a quicker repetition of them.

WHY the sentient principle, in consequence of a painful sensation, does not keep such muscles as are irritated in a continued state of contraction, but allows them to be alternately relaxed, shall be afterwards explained.

IF the contraction of an irritated muscle were owing to the action of the *stimulus* upon it as a mere mechanical organ, then, so long as the *stimulus* continued to act equably, the muscle ought to remain equally contracted, and, upon its ceasing, the muscle ought to be relaxed; or rather
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the muscle, upon the first application of the *stimulus*, ought to be suddenly contracted; which contraction should become weaker by slow degrees, till at length the muscle had returned to its natural state of relaxation. If a few drops of any acrid liquor let fall on a bare muscle, or pricking it with a needle, excites it into contraction, as a mechanical cause acting upon a mechanical organ; then, so long as the cause acts on the organ, the effect must continue to follow; and if the cause becomes gradually weaker, so also must the effect, till it ceases altogether, *i. e.* the muscle ought not to be agitated with alternate convulsive motions; but, after its first and strongest degree of contraction, it should begin to lose some of its force, and continue to do so, till it returned again to its natural state.

WHAT most resembles muscular contraction from an irritation, is the falling or closing of the leaves of the sensitive plant after being touched: but this equally happens, whether these leaves be touched with the sharp point of a penknife, or the blunt end of a pencil, with a piece of smooth wax

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or rough iron, with brandy or with water. Here, there are no alternate contractions and relaxations, as in the muscular fibres of animals; no indication of feeling or of being peculiarly affected by stimulating substances; but all is effected by mere contact or mechanical impulse. I cannot help observing in this place, though foreign to my present purpose, that the closing of the leaves of the sensitive plant upon their being touched, cannot be owing, as some have lately imagined, to the electrical matter issuing from them; since the touch of wax, which repels this matter, makes them close as remarkably, as that of *non-electric* bodies: nay, a piece of wax strongly electrified by rubbing, made the leaves of this plant quickly close, by attracting them to it with a considerable force.

IF it be said, that the elastic fibres of the muscles, or the nervous fluid supposed to be contained in their cavities, are excited by *stimuli* into strong oscillations, which are repeated till the irritation ceases, or even for some time after; I answer,

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α THAT it is not easy to conceive how such *stimuli* as do not act by any mechanical force, but merely by their acrimony, should excite an oscillatory motion in the supposed elastic fibres of the muscles, or in the animal spirits lodged in them. But not to insist on this,

β IF the motion of our muscles from a *stimulus* were owing to elastic vibrations of any kind whatever; how could the *sphincter pupillæ* and the muscles of the internal ear, continue uniformly and equally contracted for a considerable time, which they never fail to do, when the *stimuli* affecting them act with unvaried force? And why ought they not rather to be agitated by a number of quickly repeated contractions? Nay, the continued, uniform and equal contraction of the voluntary muscles would be impossible, if their motion was owing to any elastic oscillations.

γ IF muscular motion from a *stimulus* were the effect either of the vibrations of the nervous fluid or of the solid elastic fibres of the muscles themselves, the alternate contractions of an irritated muscle, like
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the vibrations of elastic bodies, ought to follow one another at equal intervals, nor would they be more slowly repeated as they become weaker, and were about to cease; which however is the case. — A musical chord, a bell, or any other elastic body, performs its vibrations in equal times, whether it be acted upon by a stronger or a weaker force; and its oscillations follow one another, from first to last, with an equal degree of swiftness: In like manner the elastic pulses which these bodies communicate to the ambient air, succeed each other as quickly in distant places, where the sound is faint, as in those near the sonorous body, where it is stronger. Since therefore the alternate contractions of irritated muscles do not follow the law of the vibration of elastic bodies, but become remarkably slower when they decrease in strength, and before they cease altogether; it follows with all the force of demonstration, that they cannot be owing to any elastic vibrations excited in the muscular fibres, or in the nervous fluid contained

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ed in them. But of this more fully afterwards*.

2. IF it were constantly observed, that such muscles only as had their fibres immediately acted upon by *stimuli*, were excited into contraction, then indeed it might be suspected with greater shew of reason, that such motions were no more than a necessary consequence of the mechanical action of those *stimuli* upon the muscular fibres: but as we find the muscles of animals brought into action without any irritation of their fibres, whenever a *stimulus* is applied to the coats or membranes covering them, to the nerves which are sent to them, or to some neighbouring or even distant part, it seems absurd to imagine such motion owing to the mechanical action of the *stimulus* upon the fibres of the muscle, and not to the impression it makes on the sentient principle. Thus the contraction of the *sphincter pupillæ* arising from the action of light on the *retina*, with which it has no communication

* Vid. sect. xiv. below on the motion of the muscles of animals when separated from the body,

tion of nerves, cannot possibly be explained mechanically, but must be owing to some sentient principle in the brain, which, excited by the uneasy sensation, increases the action of the nervous power upon that muscle. The same thing is also true of the various motions of the muscles of the *malleus* and *stapes* from different sounds striking upon the auditory nerve; and of the motions of the eye-lids as often as any thing irritates the *cornea*, be it ever so gently.—The contraction of the diaphragm and intercostal muscles, in consequence of an uneasy sensation in the lungs, must also be owing to the mind or sentient principle acting at the origin of the nerves, and not to any change wrought mechanically upon the fibres of these muscles, by the difficult passage of the blood through the pulmonary vessels. The violent action of the diaphragm and abdominal muscles in a *teneſmus* or stranguy is to be explained in the same way.—If a spark from the fire, or a drop of boiling water, falls upon one's foot, the leg is instantly drawn in towards the body; but as the muscles employed in this action

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are those which run along the thigh, and are inserted about the head of the *tibia*, it is manifest that this *stimulus* cannot excite those muscles into contraction in consequence of any mechanical action upon them ; and if the sympathy of the nerves, or continuation of membranes, shall be alledged as the cause of this motion, it may be justly demanded, why the muscles which run along the leg, and are inserted into the foot, are not more remarkably moved than those of the thigh, since they have a nearer connexion with that part to which the *stimulus* is applied ; or why the extensors of the leg are not brought equally into action with its flexors. It remains therefore that the motion of the leg, in this case, be attributed to the pain or uneasy sensation excited by the fire or boiling water, for avoiding of which the sentient principle is instantly determined to put the flexors of the leg in motion, and so to remove the member from the offending cause. Nay, where the *stimulus* is applied to the membranes or teguments covering the muscles, it seems highly probable, that the subsequent contractions
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are not owing to any change first made on their fibres: thus the convulsive motions of the intercostal and other muscles of the trunk of the body, which are excited by tickling the sides, must undoubtedly be ascribed to the mind, which, in order to avoid the disagreeable titillation, puts these muscles in action, and not to any immediate influence the tickling can have on their fibres; otherwise why should the same mechanical action of our own, and of another person's fingers, affect us so differently?—Tincture of *ipecacuanha* applied to the internal surface of the stomach, does not seem to produce the convulsive contractions of that organ in vomiting, by immediately affecting its muscular coat, which is defended by the nervous and villous ones, but by irritating its nervous *papillæ*, and thence affecting the mind or sentient principle.

SINCE, therefore, *stimuli* applied, not only to remote parts, but also to the membranes or coats immediately covering any muscle, excite it into contraction by the intervention of the mind; is it not reasonable

able to think, that even when the muscles themselves, or a few of their fibres, are irritated, the subsequent motions are owing to the mind's being excited, from a disagreeable sensation, to determine the influence of the nerves more strongly into them? This, however, will still further appear, if,

3. WE consider, that not only an irritation of the muscles of animals, or parts nearly connected with them, is followed by convulsive motions; but that the remembrance or *idea* of substances, formerly applied to different parts of the body, produces almost the same effect, as if those substances themselves were really present. Thus the sight, or even the recalled *idea* of grateful food, causes an uncommon flow of spittle into the mouth of a hungry person; and the seeing of a lemon cut produces the same effect in many people.—The sight of a medicine that has often provoked vomiting, nay the very mention of its name, will in many delicate persons raise a *nausea*; and they are affected much in the same manner when they behold any one
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under the violent operation of an emetic.—The apprenſion or fear of having one's ſides tickled, cauſes almoſt the ſame motions in the trunk of the body, while another perſon threatens or attempts it, as tickling itſelf would do, though in a leſs degree.

FURTHER, That many very remarkable changes and involuntary motions are ſuddenly produced in the body by the various affections of the mind, is undeniably evinced from a number of facts. Thus fear often cauſes a ſudden and uncommon flow of pale urine. Looking much at one troubled with ſore eyes, has ſometimes affected the ſpectator with the ſame diſeaſe.—Certain ſounds occaſion a ſhivering over the whole body.—The noiſe of a bagpipe has raiſed in ſome perſons an inclination to make urine.—The ſudden appearance of any frightful object, will, in delicate people, cauſe an uncommon palpitation of the heart.—The ſight of an epileptic perſon agitated with convulſions, has brought on an epilepsy; and yawning is ſo very catching, as frequently to be propagated through

whole companies. In these cases, the motions produced in the vessels of the eyes or eye-lids, in the heart, stomach and bladder, in the secretory vessels of the salivary glands and kidneys, in the muscles employed in yawning, &c. cannot be owing to the mechanical action of the causes above mentioned upon the fibres of the parts moved: for what particular connexion is there between the optic and auditory nerves, and those which serve the heart, stomach, bladder of urine, mouth, salivary glands, and the muscles which depress the lower jaw and move the trunk of the body? All the nerves do not at last terminate in a point, but in a large space of the brain; wherefore the consent between them cannot be deduced from their contiguity, but must be owing to a sentient PRINCIPLE, which is present, AT LEAST, wherever the nerves have their origin, and which, accordingly as it is variously affected, produces motions and changes in different parts of the body.

If then external causes affecting the brain, do, by the intervention of the mind

or sentient principle, produce remarkable changes in the muscles of spontaneous as well as of voluntary motion; and if the *idea* of a *stimulus* has, in many cases, almost the same effect as the thing itself; is it not highly reasonable to think, that stimulating substances applied to the muscles of animals excite them to contract, not by any immediate mechanical action upon their fibres, not by producing an unintelligible explosion or effervescence, or exciting strong vibrations in any ethereal or electrical matter supposed to be lodged in these fibres or their nerves; but by disagreeably affecting the sentient PRINCIPLE, in consequence of which it increases the action of the nervous power upon the fibres of those muscles which are stimulated. And there is the less reason to hesitate in admitting this doctrine, since the various *phænomena* just now recited seem undoubtedly to prove the presence, agency and very extensive influence of SOMETHING in the bodies of animals, of a nature different from, and of powers superior to mere matter, however modified, compounded or arranged.

IF *stimuli* excite the muscles of animals into contraction by acting upon them, rather as sentient than *mere* mechanical or material organs, it is easy to see, why the mildest aliment is apt to occasion vomiting when the coats of the stomach are inflamed, and why the heart is agitated with violent convulsions and palpitations as often as itself, or even the *pericardium*, is affected with any degree of inflammation. In these cases the stomach and heart are rendered extremely sensible and impatient of any irritation; whence the *stimuli* which were in use to affect them very gently, now excite them into violent convulsions.

It has been observed above, that those muscles to whose fibres *stimuli* are applied, do not remain contracted for any considerable time, but are agitated with alternate contractions and relaxations. Thus any of the muscles of the eye, by irritating their tendinous fibres with the point of a file, are set a beating almost like the heart of an animal affected with strong palpitations *. But

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* M. Senac has fallen into a mistake with respect to this matter, when he affirms that an irritation makes the muscles
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in muscles whose contraction is owing to the action of a *stimulus* upon some distant or neighbouring part, there is a diversity observed; some of them being uniformly contracted while the irritating cause lasts, others alternately contracted and relaxed: thus the action of light and sound upon the
retina

of living animals only perform one contraction, although the same cause produces many repeated contractions in the muscles of those that have been newly killed †; for, besides the instance of the muscles of the eyes here mentioned, the heart of an animal is observed to be agitated with violent and quickly repeated convulsions when it is pricked with a sharp instrument immediately upon opening the *thorax*; and, if any other muscle of a living animal be laid bare, it will, by irritating its fibres or membranes, be brought into alternate contractions. A *stimulus* therefore applied to the muscles of animals excites them, if it be any ways considerable, into alternate repeated contractions, whether the animals be alive or newly killed; only the convulsions in the former case are stronger and more remarkable than in the latter. Nay, it will be difficult to reconcile this supposed difference in the effect of an irritation on the muscles of living and newly killed animals, with that principle which this learned author has laid down, namely, that the contraction of an irritated muscle is owing to the reaction of the animal spirits lodged in its fibres, in consequence of the action or impression of the *stimulus* upon them; for there does not appear any reason why the reacting power of the animal spirits should continue to exert itself longer or more remarkably in the muscles of dead animals, than in those of living ones.

† *Traité du cœur*, vol. 1. p. 453.

retina and auditory nerves, produces an equable constant contraction of the *sphincter pupillæ* and muscles of the internal ear; while an irritation of the membrane of the nose and *trachea* is followed by alternate convulsive motions of the muscles of respiration; and a titillation of the inferior extremity of the gullet, by repeated contractions and relaxations of the diaphragm.

THESE very different effects of *stimuli* on different muscles and organs of the body, which I may venture to pronounce altogether inexplicable upon any mere mechanical theory, are easily accounted for from the principles already laid down; for if the contraction of an irritated muscle be owing to the uneasy sensation excited by the *stimulus*, as often as the first contraction does not remove this, the muscle will be agitated with alternate convulsions, as being most proper to throw off the irritating cause. If indeed, by the first contraction, the disagreeable sense of irritation be quite removed, no further motion follows; but if it still remains, new convulsive contractions will succeed, and continue to be repeated alternately,

nately, till the *stimulus* either ceases entirely, and is no longer felt, or becomes too weak to produce a new contraction. But when the contraction of any muscle occasioned by the action of a *stimulus* on a neighbouring part, would, if it was alternate, neither tend to remove the irritation, nor render the mind less sensible of it, in that case no sudden relaxation follows, but the muscle remains equally contracted as long as the stimulating cause continues the same. Let us now see how this general doctrine can be applied to the different spontaneous motions of animals.

THE alternate contractions and relaxations of the muscles of respiration in sneezing, are most wisely adapted to remove the irritating cause from the membrane of the nose, and to lessen the uneasy sensation arising from it: if, by the air, first strongly inspired and immediately after more forcibly expelled through the nose, the *stimulus* affecting its nerves be removed, no new contraction ensues; if not, the action of sneezing is still repeated, till the titillation in the nose ceases, or becomes too weak to produce

a new convulsion. In sneezing, inspiration is only performed in order to make way for the succeeding violent expiration, which most effectually removes the uneasy sensation or irritating cause ; at the same time, the strong and sudden contraction of the inspiratory muscles, acts, partly, as a kind of *stimulus* in exciting the subsequent convulsive motion of the expiratory ones,——The alternate contractions of the diaphragm in the hiccup, and of the muscles of respiration in coughing, evidently tend to remove or lessen the uneasy sensation in the gullet and *trachea*, and are therefore not continued, but interrupted by alternate relaxations. On the other hand, a strong irritation of the *intestinum rectum*, from too great a quantity of excrement, produces a continued contraction of the abdominal muscles and diaphragm, because, in this case, the contraction of these muscles has no effect to lessen the uneasy sensation, till the *faeces* are expelled. 'Tis true indeed, that when one is costive, several efforts of the diaphragm and abdominal muscles are required before any of the excrement is expelled ; but the
action

action of these muscles is, in this instance, interrupted, not on account of the irritation in the *rectum*, but in order to carry on respiration, which cannot long be suspended without occasioning a most uneasy sense of suffocation in the lungs, by which we are more strongly affected than by the *stimulus* of the *facies*.

THE causes which produce the erection of the *penis* *, though they be generally excited into action by the *stimulus* of the seed, yet do not act by alternate fits, because the erection has no immediate effect to lessen the stimulating cause: but the contraction of the *musculi ejaculatores seminis* is alternate, because by each convulsive motion, the *semen*, i. e. the irritating cause, is expelled.—The orbicular muscle of the *uvea*, and the muscles of the *malleus* and *stapes*, remain equally contracted, while the same degree of light and sound is applied to the eye and ear, because their contraction does not hinder these causes from acting uniformly and equally upon the *retina*

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* See above, Sect. vi. N^o 4.

and auditory nerve ; but no sooner is more or less light applied to the eye, or a stronger or weaker sound to the ear, than these muscles are more contracted or somewhat relaxed.—With respect to the heart, as the returning blood or irritating cause is alternately received into its cavities and expelled out of them, it is easy to see why it should, like the *ejaculatores seminis*, be agitated with regular alternate contractions. And as, by the *systole* of every portion of the guts, the air, aliments, &c. are pushed into the succeeding ones, the motion here must also be alternate ; only not so equal and regular as in the heart, where the alternate action of the irritating cause is more uniform and unvaried. On the other hand, the bladder in expelling the urine, acts not alternately, because the *stimulus* remains present with it, and an alternate motion of that organ would not have been so well adapted for the expulsion of the urine as its continued contraction.

WHEN the fibres of a muscle are irritated, by tearing them with a sharp instrument

ment or otherwise, a strong convulsive contraction instantly ensues ; which is suddenly followed by a relaxation, because an uniform continued contraction would not be so well fitted to drive off the offending cause from the muscle, as alternate contractions and relaxations : and we are so framed by the all-wise AUTHOR of nature, as spontaneously, and without any previous reflexion, to perform those motions and actions which tend most effectually to the preservation of our bodies. It is probable, however, that the alternate relaxations of irritated muscles may be owing to the uneasy sensation's being some way lessened by each contraction *, on account of which, the
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* If any one doubts that the disagreeable sensation, excited by the irritation of a muscle, will be less sensibly perceived during its contraction, let him consider that brutes, by the motion of their *panniculus carnosus*, not only drive off most effectually flies and other insects which vex them, but, by the very action of this muscle, seem to be rendered less sensible of the tickling. That friction of a part lessens, in the mean time, any itching or painful sensation in it ; and that people, whose bodies are uneasy, often change postures, because, during the motion of the parts necessary to this change, they are less sensible of the uneasiness.

sentient PRINCIPLE, as being now less affected, immediately allows the muscle to be relaxed. This is manifestly the case in the hiccup, where the convulsions of the diaphragm weaken or suspend, for some little time, the sense of irritation in the inferior extremity of the gullet. The relaxations, however, of stimulated muscles do not last for any considerable time, but are quickly succeeded by new contractions, because the painful sensation soon begins again to affect the mind more strongly: but as the irritation becomes gradually weaker, these alternate contractions will not only grow feebler but succeed one another more slowly; for while the irritation is strong, the muscle is no sooner relaxed, than its contraction is immediately renewed: whereas a weaker *stimulus* requires a longer time to operate, before it excites such an uneasy sensation as is required to produce a convulsive contraction of the part. Thus when the *thorax* of a living animal is laid open, and the heart is pricked with a sharp instrument, its contractions are greatly quickened; nay, they return so frequently, that, during their remission,

remission, very little blood enters the ventricles. Hence the sides of the heart make very small motions at first, nor are they ever fully dilated, their contractions being repeated almost as soon as their *diastole* begins; but when the impression of the *stimulus* begins to be weakened considerably, the contractions and relaxations of the heart being performed more slowly, the blood has time to dilate the ventricles more, whose sides, therefore, now make larger and more sensible motions. From what has been said, it is easy to see, why, if the blood be rendered acrid, or the heart much more irritable than usual, the pulse becomes small, fluttering and quick.

WHILE therefore the voluntary muscles, which are contracted in consequence of an effort of the will, remain in that state as long as the will continues to determine the influence of the nerves into their fibres; irritated muscles, whose contraction is owing, not to will or choice, but to an uneasy sensation, are entirely regulated by this; and as each contraction tends to lessen the disagreeable

agreeable perception, they will be agitated with alternate convulsions,

UPON the whole, as nature never multiplies causes in vain, it seems quite unphilosophical to ascribe the motions of the muscles of animals from *stimuli* to any hidden property of their fibres, peculiar activity of the nervous fluid, or other unknown cause; when they are so easily and naturally accounted for, from the power and energy of a known sentient PRINCIPLE.

S E C T. XI.

Of the share which the mind has in producing the vital and other involuntary motions of animals.

THAT all the motions of animals were by some of the ancient philosophers ascribed to the energy of a living principle wholly distinct, as to its nature, from the body, the passage of *Cicero* prefixed to this Essay clearly shews. And it was the difficulty

culty of accounting for the motion of the heart from mechanical principles alone, which made no less a philosopher among the moderns than *Borelli* doubt, whether it were not rather owing to the mind, than to any natural necessity arising from the structure of that organ or its nerves*. The great Mr *Leibnitz*, in a letter to *Michelloti*, goes still further, and supposes that the natural motions may be owing to some impressions made on the mind, although we are no ways conscious of these†. It is true Dr *Stahl*, by extending the influence of the soul, as a rational agent, over the body a great

* De motu animal part 2. prop. 79. & 80.

† *Michelloti*. de separatione fluidor p. 351.

Indeed, strictly speaking, it is inconsistent with Mr *Leibnitz*'s principles to ascribe any of our motions, either voluntary or involuntary, to the mind; since, according to his pre-establiſhed harmony, the soul neither acts on the body, nor is affected by the impressions of external objects. This ingenious fable, however, which novelty, I suppose, at first recommended, has been so fully refuted by Mr *Bayle* and others, as to make it needless for us to attempt to shew its weakness: but we cannot help observing, that it is matter of wonder how a doctrine, which explains nothing, and is loaded with so many difficulties, should still have any advocates.

great deal too far, and thus carrying this doctrine beyond all reasonable bounds, has been the occasion, why it has, for many years, been looked upon rather as a subject of ridicule, than deserving a serious and rational answer. However, that the motion of the heart and circulation of the blood, are altogether inexplicable upon principles purely mechanical, there are arguments *à priori* which seem to demonstrate *. But, as this kind of reasoning, in matters not capable of strict demonstration, frequently betrays us into error and mistakes, we shall further endeavour to vindicate this opinion from the most plausible objections which may be brought against it; and at the same time shew by a variety of arguments *à posteriori*, chiefly of the analogical kind, that the vital, as well as the other involuntary motions of animals, are directly owing to the immediate energy of the mind or sentient principle.

THE

* See *Edinburgh Medical Essays*, vol. 4. art. 14. where an argument of this kind has been proposed with great strength and perspicuity by the learned Dr *Porterfield*.

THE chief power propelling the blood through all the vessels of the body, is the contraction of the heart. But from Dr *Hales's* experiments it appears, that, in every circulation, the blood loses $\frac{2}{10}$ of the *momentum* communicated to it by the left ventricle of the heart *; wherefore there must be in every animal some cause, which repairs this loss of motion arising from friction, &c. *i. e.* a cause generating motion; but, as has been observed above, matter, in its own nature inert, is incapable of this. Further, such animals as lie in a dead inactive state during the cold winter-season, and whose blood has lost all its motion, may at any time be restored to life by warmth; which rarifying their stagnating fluids, and communicating to them a small degree of intestine motion, excites the heart into action; whose motion, though it be at first very languid, yet gradually gains strength, till at last it arrives at its wonted vigour. As, in this case, the renewal of the heart's motion, and its gradual increase, cannot be explained

* Statical Essays, vol. 2.

explained from any mechanical principles; since we have not only a cause producing an effect greater than itself, but also an effect increasing by degrees, and, as it were, of its own accord: it follows, that there is in these animals some living principle, which being, by the *stimulus* of warmth, roused, as we may say, out of a state of indolence, brings into gentle contractions the *sinus venosi*, auricles and ventricles of the heart; which are parts of the body most sensible of the irritation of the fluids when rarified and agitated by heat.

THE contraction of the heart, so far as it is owing to a material cause, seems to proceed from the action of the nervous power upon its fibres: but as, perhaps, $\frac{1}{100000}$ part of the blood thrown out by the left ventricle of the heart, does not return to it again in the form of vital spirits, as they are called; and as the motion of this fluid must be incredibly diminished by its passage through the vastly subtile vessels of the *cerebellum*, &c. there can be no force in these spirits derived from the last *systole* of the heart sufficient to produce a new contraction

tion of this muscle, since no cause can generate an effect greater than itself.

AGAIN, The human body, in which there is no mover that can properly be called FIRST, or whose motion depends not on something else, is a system far above the power of mechanics. The contraction of the heart is indeed the cause of the blood's motion, and consequently of the secretion of the spirits (as is supposed) in the *cerebellum*, &c.; but without these spirits, this action of the heart could not be performed: these two causes, therefore, truly act in a circle, and may be considered mutually as cause and effect. Whence it is incumbent on those Philosophers who ascribe the heart's motion to mechanical causes alone, to demonstrate the possibility of a *perpetuum mobile*, since, as long as life lasts, an animal is really such. But as a perpetual motion is, in the opinion of the ablest Philosophers, above the powers of mechanism, and inconsistent with the known laws of matter and motion *, we must be allowed to

* "Ex calculo mechanico liquet omnem de motu perpetuo
"questionem eò redire, ut inveniatur pondus seipso ponderosi.
"us,

to conclude, that the contraction of the heart, and the propulsion of the blood through the body, and consequently the continuance of life, are not owing to any mechanical or even material causes alone; but to the energy of a living principle capable of generating motion.

How far the mind is really concerned in the motion of the heart, may easily appear from what has been already offered in the preceding Sections; where, if I mistake not it has been shewn, beyond doubt, that the contraction of the heart is owing to the returning venous blood acting as a *stimulus* upon it; and made highly probable, both from reason and analogy, that a *stimulus* excites our muscles into motion, only as they are animated by a sentient principle. Whence it must follow, that the alternate contractions of the heart are in no other sense owing to the irritation of the returning blood, than as the mind or sentient principle is, by this, excited to increase

“us, vel vis elastica seipsâ fortior.” *Clarkii* not. in *Rohault. physic.* § 1. cap. 22.

crease the action of the nerves upon its fibres.

THIS doctrine of the alternate motion of the heart as proceeding from the power of the mind, excited into action by the *stimulus* of the returning venous blood admitted into its cavities, is greatly strengthened by the account we have given of the alternate motions of respiration, of the contractions of the muscles of the internal ear and of the pupil. These we have clearly shewn to proceed from the mind, as affected by a *stimulus*, and to be altogether inexplicable upon principles merely mechanical. The first of these motions (*viz.* respiration) agrees with that of the heart, in being performed whether we attend to it or no, and whether we sleep or are awake; although it differs from the motion of the heart, in being under the dominion of the will. The motions of the *iris* from light, and of the muscles of the ear from various sounds, differ from those of the heart, as they are not vital, nor continually and alternately excited by causes within the body, but owing to external causes acting at particular times

times on the organs of sight and hearing : these muscles, however, exactly agree with the heart in this, that their motions are altogether involuntary, and cannot be controuled by any immediate effort of the will. Since then, in the muscles of respiration, we have an instance of a vital, though not altogether involuntary motion, proceeding from the mind ; and, in the muscles of the *uvula* and ear, examples of motions, which, though not vital, are yet wholly involuntary, owing to the same cause ; may we not, if it be in the least allowable to argue from analogy, safely conclude, that the contraction of the heart, which is both vital and involuntary, is ultimately to be referred to the sentient principle excited to put this muscle in motion by the irritation of the venous blood acting upon it alternately ? What has been said of the motion of the heart, as proceeding from the mind, is equally applicable to the peristaltic motion of the stomach and intestines, and to the rest of the vital or involuntary motions.

ALTHOUGH

ALTHOUGH what has been already offered, might be sufficient to shew, that all the motions of animals, involuntary as well as voluntary, are some way owing to the mind ; yet as this doctrine may appear to some, who have always been used to think in a different way, as beset with many difficulties ; and as there may not be wanting those, who are unhappily more tenacious of received opinions than willing to embrace such as are true ; we shall briefly obviate some of the strongest objections, which, at first sight, seem to lie against it ; and this we shall do the more willingly, as an opportunity will hence be afforded us of illustrating, still further, the nature and cause of the involuntary motions of animals.

Objection I. IT may be said, that, while we ascribe the vital and other involuntary motions of animals to the mind, we, in fact, attribute them to a power, whose nature and manner of acting we are ignorant of*.

Answer. THAT there is united to the bodies of men and animals an active, living, sentient principle, which is the cause of voluntary

* *Senac* Traité du coeur, vol. 1. p. 441. & 445.

luntary motion, it may be hoped there are few Philosophers, now a-days, so MINUTE as to deny : and, if it be thought no absurdity to ascribe voluntary motion to the energy of the mind, though we do not understand its nature or manner of operation, why should it be reckoned such, to derive the vital and other involuntary motions from the same source ; especially, when a variety of *phenomena* and the strongest analogy concur in supporting this opinion ? That there is such a thing as gravity, or attraction betwixt the parts of matter, is a thing not to be doubted of, because we see its effects, though its cause be unknown : and, if Philosophers make use of this power every day, with the greatest justice, in order to explain the *phenomena* of nature, why should it not be thought equally reasonable to have recourse, in accounting for the motions and actions of an animated body, to the power and energy of the mind, which we are sure is always present with it, and in numberless instances operates upon it ? In an attempt to account for the surprising operations and effects of an inanimate machine,

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it would be thought highly ridiculous to have recourse to the agency of an immaterial living principle: and must it not be equally so, to banish the consideration of *mind* in explaining the *phænomena* of an animated system; or to endeavour to deduce its most remarkable motions from the mere material part?

THERE is no need of understanding the nature of the soul, or the way in which it acts upon the body, in order to know that the vital motions are owing to it: it is sufficient, if we know from experience, that it feels, is endued with sensation, and has a power of moving the body *.

EVERY attempt hitherto made towards deducing the vital motions of animals from powers wholly material, has been unsatisfactory; and, I may venture to say, will be for

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* The reader will easily perceive, that the objection against deriving the vital motions from the mind, because we are not fully apprised of its nature and manner of acting, may be retorted with double strength upon those, who ascribe the contraction of the heart to some latent power in it, or to the oscillations of an unknown fluid supposed to be lodged in its fibres and nerves *.

* *Senac traité du coeur*, vol. 1. p. 434. & 52.

ever vain : since it has not only been proved, that they are above the force of mechanism, but also that the supposition of any mere material power's being their cause, is by no means suitable to the *phenomena* we observe. Nor can I conceive the reason why Physicians have laboured so long in accounting for the action of the heart and other vital motions of animals, from the powers and properties of body independent of mind : if it be not, that in some, the leaven of Cartesianism still continues to work ; in others, a too great fondness for mechanical reasoning in Physiological matters ; and in both, a contempt of the extravagant notions of *Stahl* and his followers, with regard to the manner in which the mind regulates all the actions of the body *.

MANY

* I have not met with any author, who has embraced the STAHLIAN doctrine with less reserve, or carried it to a more surprising height, than the learned Dr *Nicholls*, in his elegant *Prælection de Anima medica*. According to him, the soul at first forms the body, and governs it ever after, carrying on and regulating all its vital and natural motions ; distributing the fluids with greater or less force to its several parts, and exciting in them, from time to time, such commotions and changes, as she sees most proper for removing their various disorders.—

MANY Philosophers have supposed two distinct principles in man; one of which has been called the *anima*, or soul; the other, the *animus*, or mind; by the former, they

disorders.—He ascribes it to the prudence of the soul, that the *semen* is not perfected in males, till the body hath acquired strength and vigour sufficient for the work of generation: and he finds a wonderful instance of her sagacity, in the slow and gradual eruption of the small-pox; as the force of the disease is hence divided, and its danger greatly lessened.—When the body is disordered, or exhausted with fatigue, the soul frequently hides herself in sleep, and retires from external things, in order that she may be more at leisure to recruit the body, or to rectify what has happened amiss in it; and hence the inclination to sleep after child-bearing: hence, also, the frequent sleeping of infants; whose *anima*, it seems, is so taken up with directing and governing the vital motions, that it has little time to attend to any thing else.—The soul, however, seems to neglect, in a great measure, this province, as often as she is too much distracted with external things; and hence it is, that health is so much impaired by fear, sorrow, love, and other more violent passions: nor is she without her wilful and forward fits; as appears from her sending the milk back into the blood from the breasts of pregnant women, whose *fætuses* she had only fancied were suddenly dead, and from her not deriving into them again those nourishing streams, when living children are really born; as if, for her part, she had rather they were starved, than that she herself should seem to have been under mistakes.—In fevers, the sudden failing of the strength and pulse ought, we are told, to be regarded by us as signs of the despairing soul's discontinuing her care of the body, and

they understood the principle of life and sense influencing the vital motions; and by the latter, the seat of reason or intelligence. According to them, we have the *anima*, or
vital

and being soon about to relinquish it: nay, sometimes, like a mean and silly coward, she sinks even under such diseases, as, in their own nature, are not at all deadly; and, through false alarms, she is either thrown into a great hurry and trepidation, which urges her to make wild work of it, and to do much mischief; or else she becomes very backward and remiss in her endeavours to preserve the body, and, as if it were a FIELD not worth keeping, foolishly deserts it: though, were she but always wise enough, and, neglecting things of less moment, were solely intent on the preservation of the body, she could, if we may believe the Doctor, not only prevent diseases, as far, at least, as they proceed from internal causes, but protract also the life of man, it may be, to a thousand years: a TERM greatly beyond what the ADEPTS promised themselves from their *aurum potabile*, or UNIVERSAL REMEDY.

But, as this account of the agency of the soul, and of its power over the body, scarcely seems to demand a serious answer, I shall only observe, that to imagine the soul should, with the wisest views and in the most skilful manner, at first form the body, (a work far above the utmost efforts of human art and contrivance!) and afterwards, when it is disordered, should, with the same skill and wisdom, often remedy the evil, and restore it to a sound state; but finding it in the end, or sometimes suspecting it only, to be no longer tenable or comfortable, should, instead of repairing, either whimsically or wisely desert it: to conceive, I say, of the soul as performing all this, without, in the mean time, being consci-

vital and sentient soul, in common with the brutes ; but the *animus* or *mens*, which is of a more exalted nature, is proper to rational creatures alone *.

SOME modern Materialists have imagined the *anima* to be no other than a more subtile kind of matter lodged, chiefly, in the brain and nerves, and circulating with the grosser fluids. But such spirits, or subtile matter, can no more be acknowledged the vital principle or source of animal life, than the blood from which they are derived ; and still with less reason can this material *anima* be supposed endued with sense, since
matter,

ous of such intentions, or of the exertions of its power in pursuance of them, is at least as great a stretch of fancy, as to suppose, that an able architect might raise a stately edifice, in which nothing should be wanting that could contribute either to its usefulness or ornament ; that he might frequently make good such damages as it sustains from the weather, or from the decay of any of its materials ; and at last, apprehending it to be in danger of falling, might abandon it ; without being at all aware of ever having once exercised, either his skill in contriving, erecting, and repairing it, or his prudence in quitting it, when, as he thought, it was ready to bury him in its ruins.

* ——— *Indulſit communis conditor illis*

Tantum animas, nobis animum quoque.

JUVENAL. Sat. 15. lin. 148. & 149.

matter, of itself, and unactuated by any higher principle, is equally as incapable of sense or perception, pleasure or pain, as it is of self-motion. Indeed, a few authors have run such lengths, as to suppose even the *animus*, or rational soul itself, material: but surely the powers and faculties of the mind are not to be found in matter, or in any of those principles, or elements, whereof either the ancients or moderns have imagined it to consist: fire itself, the most subtile and active among these, being as incapable of thought and reflexion, as water or earth, the most sluggish*: and in what manner self-motion, sense or reason can possibly result from the circulation of the spirits in the brain, or from the peculiar

* “ *Animorum nulla in terris origo inveniri potest. Nihil enim est in animis mixtum atque concretum, aut quod ex terra natum atque fictum esse videatur: nihil ne ut humidum quidem, aut stabile aut igneum. His enim in naturis nihil inest, quod vim memoriæ, mentis, cogitationis habeat, quod et præterita teneat, et futura provideat,* et complecti possit præsentia.*” *Cicero in Tusculan. disput. lib. I.*

See also, in proof of the immateriality of the soul, Dr *Sam. Clarke's* defences of his letter to Mr *Dodwell*, where *Perspicuity*, *Metaphysics*, and *sound Philosophy*, are happily united,

cular structure, connexion, situation or arrangement of the various parts of the body, (without supposing a mind) is a point which the abettors of Materialism, will never be able to clear up *.

FURTHER, if the DEITY be incorporeal (as is allowed by some of the ablest advocates for the materiality of the human soul) and if he can create intelligent beings that are not *material*, is it not entirely agreeable to the analogy of Nature, to consider animals, (which hold as it were the middle-rank, in the creation, between purely spiritual intelligences and substances that are wholly corporeal) as deriving their sentient and rational powers, not from that inert matter, however curiously wrought up or modified, of which their brain and nerves are composed, but from an intelligent, incorporeal *principle* animating their bodies?

UPON the whole, as I cannot agree with those, who, in ascribing all our powers to
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* “Membrorum verò situs et figura corporis, vacans animo, quam possit harmoniam efficere non video.” *Cicero*n. *Tusculan. disput. lib. i.*

mere matter, seem willing to deprive us wholly of mind; so neither, at the same time, do I see any reason for multiplying principles of this kind in man; and, therefore, I am inclined to think the *anima* and *animus*, as they have been termed, or the sentient and rational soul, to be only one and the same principle acting in different capacities. Nay, *Epicurus* himself, according to *Lucretius*, did not look upon these two as separate beings, but regarded the mind as a kind of *mouvement* produced by the *anima* or soul*.

THAT the involuntary motions in man are not owing to a principle distinct from the rational soul, seems evident, from the muscles and organs, whose action has been generally ascribed to the *anima*, being, in many cases, subject to the power of the *animus* or rational principle; as well as, on the other hand, from the motions of the voluntary muscles often becoming involuntary, or independent upon the will. Thus
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* *Nunc animum atque animam dico conjuncta teneri
Inter se, atque unam naturam conficere ex se.*

the diaphragm, whose motions in the hiccup are altogether involuntary, and in ordinary respiration go on without our consciousness of them, is nevertheless subject to the immediate influence and direction of the mind ; since its motions in breathing can, by an effort of the will, either be augmented or lessened, retarded or accelerated.—The evacuation of the *intestinum rectum* and bladder of urine, which, when the *stimulus* is gentle, is in part voluntary, becomes altogether involuntary and convulsive, when the irritation is greater.—The eye-lids, over which the mind seems to have a full power, move, commonly, not only without our attention, but, in some cases, even against every effort of the will to the contrary.—The action of the *acceleratores urinae* is voluntary in expelling the last drops of urine ; but in expelling the *semen*, it is involuntary.—The contraction of the pupil, which, in order to distinct vision, is voluntary, becomes altogether involuntary when owing to an increase of light. In short, there is not a voluntary muscle in the body, whose motion does not become

involuntary, as often as it is either directly, or from its consent with some neighbouring part, affected by any considerable *stimulus*: if the irritation be very gentle, we still retain a greater or less power over the muscle; but when it becomes stronger, we lose all this power.

FURTHER, in man the sentient and rational principle must be acknowledged to be one; since we are all conscious that what feels, reasons, and exerts itself in moving the body, is one and the same, and not distinct beings. It is the mind, therefore, that feels, thinks, remembers and reasons; which, though one principle, is nevertheless possessed of these different powers, and acts in these different capacities; nay, since memory is as widely different from the present perception of ideas, or the exertion of the will in order to action, as sense is from reason, it might with equal propriety be maintained, that we are endowed with four souls, namely, with a rational, a reminiscent, an active, and a sentient one, as that we have two.

IN brutes of the lowest kind there is evidently a sentient principle: but it seems to be wholly devoid of reason or intelligence: in those, however, of a higher class, we can perceive faint traces of something like what we call reason and reflection in man. Why, therefore, may not the human mind, which enjoys all the powers belonging to the souls of the lowest creatures, and has also reason superadded to those powers, be allowed sometimes to act as a sentient, and at other times as a rational being, *i. e.* in different capacities?

BUT, if any one yet contends, that the sentient principle, governing the vital motions, is different from the rational, I shall not think it much worth while to dispute the matter with him: since whatever is advanced, in the present ESSAY, upon the subject of the involuntary motions of animals, will hold equally true, whether the sentient and rational soul be supposed distinct, or otherwise.

HOWEVER, although we conceive it to be the most probable opinion, that the sentient and rational principle in man are one
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and the same; yet we think it a very clear point, that the mind does not, as Dr *Stahl* and others would persuade us, preside over, regulate and continue the vital motions, or, upon extraordinary occasions, exert its power in redoubling them, from any rational views, or from a consciousness that the body's welfare demands her care in these particulars: for infants, ideots, and brutes of the lowest kind, (which last are certainly destitute of reason), perform those motions in as perfect a manner as the wisest Philosopher; and the mind, when life is endangered by the too violent circulation of the blood, neither does, nor can moderate the heart's motion. If the contraction of the heart were owing to any previous deduction of reason, or conviction of its being necessary to the continuance of health or life, the mind ought to have a power of restraining the uniform motions of its auricles and ventricles, or of repeating them at shorter or longer intervals, notwithstanding their having become, like those of the eyes, in a manner necessary through long habit: for though we cannot, indeed, move our eyes
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in every different direction, yet we can restrain or vary their uniform motions as we please.

FURTHER, if there were any exercise of reason necessary to the continuance of the vital motions, the mind ought certainly to be conscious of this; since, in every ratiocination respecting action, there must first be a comparison of things, and then, in consequence of this comparison, a preference or election: but, I believe, few Philosophers will be found hardy enough to maintain, that the mind can compare two, or more ideas, and thence form certain conclusions and determinations, without being so much as conscious, in any degree, of what it has been all the while employed about: for though, when we are solicitously engaged in any action, deeply involved in any thought, or strongly hurried away by any passion, we may often be unconscious of the impressions made by material causes on the organs of sense*; yet we cannot but be sensible of
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* To avoid all metaphysical disputes about different degrees of consciousness; I desire it may be understood, that
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the ideas formed within us by the internal operation of our minds, because their very existence depends upon our being conscious of them, and is at an end, as soon as either we attend not to, or forget them: to say therefore that such ideas may be formed and exist in the mind without consciousness, is, in effect, to say that they may, and may not exist at the same time; than which nothing can be more absurd.

ADD to this, that the motions excited by any pain, or irritation, are so instantaneous, that there can be no time for the exercise of reason, or a comparison of ideas in order to their performance; but they seem to follow as a necessary and immediate consequence of the disagreeable perception. And as the DEITY seems to have implanted in our minds a kind of SENSE respecting *Morals*, whence we approve of some actions, and disapprove

here and in other parts of this Essay, when I say we are not conscious of certain impressions made on the mind by the action of material causes on the organs of the body, I mean no more, than that we have no such consciousness or perception of them, as either convinces us of their existence when present, or enables us, by the help of memory, to recall them when past.

disapprove of others, almost instantly, and without any previous reasoning about their fitness or unfitness; a FACULTY of singular use, if not absolutely necessary for securing the interests of virtue among such creatures as men! so, methinks, the analogy will appear very easy and natural, if we suppose our minds so formed and connected with our bodies, as that, in consequence of a *stimulus* affecting any organ, or of an uneasy perception in it, they shall immediately excite such motions in this or that organ, or part of the body, as may be most proper to remove the irritating cause; and this, without any previous rational conviction of such motions being necessary or conducive to this end. Hence, men do not eat, drink, or propagate their kind, from deliberate views of preserving themselves or their species, but merely in consequence of the sensations of hunger, thirst, &c.

THE mind, therefore, in carrying on the vital and other involuntary motions, does not act as a rational, but as a sentient principle; which, without reasoning upon the matter, is as certainly determined by an ungrateful

grateful sensation or *stimulus* affecting the organs, to exert its power, in bringing about these motions, as is a balance, while, from mechanical laws, it preponderates on that side where the greatest weight prevails.

THE general and wise intention of all the involuntary motions, is the removal of every thing that irritates, disturbs, or hurts the body; hence, those violent motions of the heart, in the beginning of fevers, small-pox, measles, &c. when frequently the blood, from its being affected by the mixture of some peculiar *miasma*, acts as a stronger *stimulus* than usual upon that organ. Nevertheless, as, in many instances, the very best things may, by excess, become hurtful; so this endeavour to free the body, or any of its parts, from what is noxious, becomes unhappily, sometimes, so strong and vehement, as to threaten the entire destruction of the animal fabric. But, in the main, this FACULTY must be confessed highly useful and beneficial; since, without it, we should constantly have cherished within our bodies the lurking principles of diseases, slowly indeed and by imperceptible degrees,

grees, but not less surely, ruining our health and constitutions.

UPON the whole, there seems to be in man one sentient and intelligent PRINCIPLE, which is equally the source of life, sense and motion, as of reason ; and which exerts more or less of its power and influence, as the different circumstances ~~of the~~ of the several organs actuated by it may require. That this principle operates upon the body, by the intervention of *something* in the brain or nerves, is, I think, likewise probable ; though, as to its particular nature, I presume not to allow myself in any uncertain conjectures ; but, perhaps, by means of this connecting *medium*, the various impressions, made on the several parts of the body either by external or internal causes, are transmitted, and perceived by the mind ; in consequence of which it may determine the nervous influence variously into the different organs, and so become the cause of all the vital and involuntary motions, as well as of the animal and voluntary. It seems to act necessarily, and as a sentient principle only, when its power is exerted in

causing the former ; but, in producing the latter, it acts freely, and both as a sentient and rational agent.

THE bodies of brute animals are actuated by a principle of a like kind with that which is placed in man, but greatly inferior with regard to the degrees of reason and intelligence which it possesses : in the more perfect brutes, this principle is plainly intelligent as well as sentient ; and their actions so evidently shew them to be endued, not only with a strong memory, but with reflexion and some degrees of reason, that it is really wonderful to find *Descartes* and his followers so far imposing upon themselves, as seriously to believe these were machines formed entirely of matter, and, as it were, so many curious pieces of clock-work wound up and set a-going. Nor is it less surprising that the generality of Theological writers should, till of late, have been so far mistaken in this matter, as not to have perceived, that, after once admitting all the actions of the most perfect brutes to result from mere mechanism, the ascribing every thing

thing in man to no higher a principle, would be a natural and easy consequence.

IN the inferior orders of brutes the appearances of reason and reflexion are more obscure ; and, in the lowest species of animals, there are no marks of intelligence, nor do we observe them to differ othewise from vegetables, than as they are endued with some degree of sensation and self-motion.

Obj. II. IT may be alledged, that the vital motions cannot be owing to *stimuli* affecting the mind in the manner above explained, since we are not conscious of any such thing.

Answer, THIS may be owing either to the gentleness of the irritation, or to our having been long accustomed to it, perhaps from the beginning of our lives.

α We all know, that such ideas as but slightly affect us, and soon give place to succeeding ones, are quickly forgot ; nay, that impressions, which are very faint in themselves, or lost amidst far stronger ones, are frequently neither attended with consciousness when present, nor remembered when past. In walking the streets, how many persons

persons of one's acquaintance are every minute presented to the mind, as their pictures are painted on the *retina*; yet if we be alone, having our thoughts strongly turned upon a particular subject, or else be deeply engaged in conversation with a friend, we are often not conscious of the presence of these people when before our eyes, nor remember their having been so, when they have left us.—If we turn our eyes towards azure sky at noon-day, we cannot, by the utmost attention, observe any of the stars; and yet it is certain, that, at that time, there are images of every star in the visible hemisphere formed upon the bottom of our eyes: for the stellar light must run through the same torrent of sun-beams to reach us in the night as in the day, allowance being only made for the inconsiderable depth of the earth's atmosphere*.

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* In this particular case, we must either suppose, that the impressions, made by the stars on the *retina*, are suffocated and lost in those stronger ones made by the illuminated atmosphere, so as never to reach the *sensorium* in order to excite any *idea* in the mind, or that if they do reach the sensory, and create correspondent ideas, yet they are so drowned, as it were, in the stronger idea, as to escape our attention and memory. I am not insensible, that there is a real difficulty in this mat-

ter,

THE sensation arising from the impetuous course of the blood through the pulmonary vessels, is, usually, so very slight, as not to be felt or attended to. But this is far from being the case in asthmatic disorders, or after respiration has been suppressed for some time; for, then, it is very remarkable, being accompanied with great uneasiness and anxiety.—The action of the air, aliments and bile, upon the intestines, which is the cause of their peristaltic motion

ter, and even some appearance of contradiction in the last supposition: for it may well be asked, what is an idea drowned in another, but a perception unperceived? Without pretending to decide, therefore, in this so very subtle a question, I shall only take notice of a fact, which, if duly weighed, would perhaps go as far towards clearing it up as any other consideration whatever. It is well known Sir *Isaac Newton* has proved, by a beautiful variety of experiments, that, from the union of simple-coloured rays, are formed compound-coloured ones; for example, that a red and yellow ray mingled make an orange; blue and yellow a green one, and so of the rest; and that all the simple-coloured rays combined form a white one. But this discovery is by no means confined to colours as they exist out of the mind, either in the rays of light, or surfaces of bodies; but is equally true of the ideas of colours in the mind itself: for it appears, by experiments that the *idea* of red, and the *idea* of yellow, confounded in the mind by co-existence or rapid succession, make the *idea* of orange; the ideas of blue and yellow, that of green, &c. and those of the seven simple colours that of white.

motion, is commonly altogether unperceived by us; but let the *stimulus* acting on the intestines be increased, as is the case when any strong purgative medicine is swallowed, or when any acrid humours are lodged in the *primæ viæ*, and it will be felt very sensibly.—The *stimulus* of light upon the *retina*, which makes the pupil contract is seldom perceived or regarded, unless it be, when the degree of light is much stronger than what the eye, immediately before, had been exposed to.—The action of the returning blood upon the heart, though it be usually quite imperceptible, seems, in some cases, plainly to be felt: for people, especially such as have weak nerves, after a sudden fright, which makes the blood return more hastily, and in greater quantity, than usual to the heart, are sensible of a particular feeling, not easy to be described in words, from this organ's being more than ordinarily affected by a surcharge of that fluid.—In various parts of the body, pulsations, or small alternate convulsions, are sometimes perceived; which, as they keep not time with the beating of the heart,

heart, cannot be arterial vibrations, but must be the alternate contractions of muscles, or, rather, of a small parcel of their fibres. There is no sensation of a *stimulus* in the part before these motions begin, or while they continue; and yet, as they frequently happen to people in good health, whose brain and nervous system are sound, it is more than probable that they are owing to some obstructing matter, which distracts the fibres of the subtiler vessels, or to acrid particles in the fluids coming into contact with the tender nerves of the convulsed part.

β THE *stimulus* occasioning the vital motions is unperceived by us, not only on account of its gentleness, but also because we have been accustomed to it from the earliest period of our lives. The force of custom is prodigious and unaccountable; what we have been long used to, we become scarcely sensible of, while things which are new, though much more trifling, and of weaker impression, affect us remarkably. Thus he who is wont to spend the greatest part of his time in the silent retirements
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of the country, is surprisngly affected, upon his first coming into a populous city, with the noise and bustle which prevail there: of this, however, he daily becomes less and less sensible, till, at length, he regards it no more than they who have been used to it all their life-time.

THE same seems to be the case, also, with regard to what passes within our bodies. Few persons in health feel the beating of their heart, though it strikes against the ribs, and that too with a considerable force every second or oftener; whereas the motion of a fly upon one's face or hands, occasions a very sensible and an uneasy titillation.—The pulsation of the great *aorta* itself is wholly unobserved by us; yet the unusual beating even of a small artery in any of the fingers, from an obstruction of its vessels, becomes very remarkable.—Although the blood rushes into the ventricles of the heart with a considerable velocity, and is thence expelled into the arteries with a much greater force; yet we are not conscious of so much as one drop of that fluid passing this way; otherwise the circulation
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of the blood could not have remained so long a secret to mankind. And if we are not sensible of the *stimulus* of the air, aliment and bile upon the intestines, which, however, all allow to be the cause of their vermicular motion; nor are immediately conscious of the action of *opium* upon the nerves of the stomach, which yet produces surprising effects over the whole body; why should it be thought strange that we do not feel the *stimulus* of the blood upon the internal surface of the ventricles of the heart, which is more gentle than the last, and which, as well as the first, custom, that second nature, prevailing from the very beginning of our lives, has rendered quite familiar and unheeded.

UPON the whole, from what has been said, it may fully appear, that there is no good reason for denying the vital motions to proceed from *stimuli* affecting the mind, because we are not conscious of this; or for imagining that the blood does not gently irritate the heart, because we do not feel a particular sensation in this organ

immediately preceding its several contractions.

Obj. III. IT may be said, that although we are insensible of the *stimuli* affecting the organs of vital motion, either from their slightness or from custom ; yet we ought to be conscious of the exertion of the mind's power in producing these motions.

Answer, α THAT a man may, in general and with propriety, be called conscious of any action, it is not only necessary he should perceive it, during the time in which it is performed, but also that he be able to recollect it after it is past : for though one be sensible, while a visible object is before him, that he sees it ; yet if he retains not the least memory of it after it is removed out of his sight, he can neither satisfy himself nor others that ever he saw it. In like manner, we cannot be called conscious of an action or volition that is not adverted to when performed, or, as soon as it is over, is entirely forgotten by us : for as there are some sensations, either so slight in themselves, or so much weakened by the diversion of our attention, that they leave no traces in the
memory ;

memory ; so there may be actions and volitions, that are either so faint, so habitual, or so much lessened amid stronger and more important exertions of the mind, that they may not only be entirely and for ever forgotten, but never so much as taken notice of or reflected upon.

β SETTING aside, however, all metaphysical considerations, we may find arguments *a posteriori* sufficient to prove that the mind does perform actions, which nevertheless are unattended with consciousness. Thus, altho' we are not conscious of any effort of the mind in producing those motions of the body, which tickling the sides or the soles of the feet excites ; yet it appears they in fact do proceed from the mind, from the like motions being produced, though in a less degree, by the fear, only, or apprehension of being tickled.—Dust, as well as flies and several other insects passing before our eyes, make us shut the *palpebræ* ; and yet these motions, which certainly proceed from the mind, are not often attended to, and seldom remembered by us.—The contraction of the pupil from light, and of the muscles of
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the internal ear from sound, has been shewn to arise from an exertion of the mind's power, of which, however, we are in no degree sensible.—As the erection of the *penis* often proceeds from lascivious thoughts; it must be ascribed, in these cases at least, to the mind, notwithstanding our being equally unconscious of its influence exerted here, as in producing the contraction of the heart.—The sight, or even the remembrance of grateful food, is accompanied with a sudden and copious excretion of spittle into the mouth of a hungry person: certain ideas excited in the mind are the occasion of an uncommon flow of tears, from the lachrymal vessels: and a nurse's breast pours out its milk when a child is brought, only, near it. The extraordinary motions of the vessels of those parts cannot in any other way be accounted for, than by ascribing them to the mind; of whose action, however, we are no ways conscious.

FURTHER, since, in consequence of certain ideas being excited in the mind, the stomach is immediately affected with a *nausea* and vomiting, it cannot be denied that
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this is owing to an increased action of the nervous influence, by means of the mind, upon the muscular fibres of this organ; yet we are not at all more sensible of an exertion of the mind's power in this case, than we are when vomiting is excited by swallowing a dose of *ippecacuanha* or emetic tartar. The want of consciousness, therefore, can be no sufficient argument against the motion of the stomach, whether natural or perverted, being produced by the active power or energy of the sentient principle, which is variously affected by the different *stimuli* applied to the delicate nerves of that organ; and if the *idea*, only, of a disagreeable sensation in the stomach, can occasion, through the influence of the mind, the motions of vomiting, why should not the real feeling of such a sensation in it, more remarkably affect the mind, and so excite it to produce similar motions.

WHAT has been said with regard to the motions of the stomach, may readily be applied to those of the heart: for no sooner are certain ideas presented to the mind, than the motion of the heart is increased
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and accelerated; which must, therefore, undoubtedly be the effect of an extraordinary action of the nervous power on its fibres consequent upon the emotion raised in the soul: yet of this effort of the mind we are not in any degree conscious. If, therefore, the mind can thus influence the heart's motion, and we, at the same time, not be sensible of its power being directed to that end, it can by no means appear unreasonable to suppose, that the *stimulus* of the returning blood may excite the sentient principle to bring the heart into contraction, although we are not in the least conscious of any such exertion of its power.

BUT, the objection against the mind's being concerned in the vital and other involuntary motions, drawn from our not being conscious of its interposing for this end, is quite overturned, by considering that a great variety even of the voluntary motions are many times performed, when we are insensible of the power of the will exerted in their production. Thus, while in walking we either meditate by ourselves, or converse with others, we move the muscles of our
legs

legs and thighs, without attending to, or knowing any thing of the matter.—We are not sensible of the eye-lids being kept open by the continued operation of the will ; but yet, when drouziness and sleep steal upon us, we find it requires a considerable effort to prevent the falling down of the superior *palpebræ*. The same thing is true of the action of the muscles which support the head. The most probable account of our ignorance of these things, which, as they are transacted within the sphere of our own bodies, it might be expected we should be well acquainted withal, seems to be this, *viz.* that we not only acquire, through custom and habit, a faculty of performing certain motions with greater ease than we were wont to do them, but also, in proportion as this facility is increased, we become less sensible of any share or concern the mind has in them. Thus a young player upon the harpsicord or a dancer, is, at first, very thoughtful and solicitous about every motion of his fingers, or every step he makes while the PROFICIENTS or MASTERS in these arts perform the very same motions, not
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only more dexterously, and with greater agility, but almost without any reflexion or attention to what they are about.

SOME indeed have gone so far, as to deny that even the voluntary motions are owing to the mind as their proper cause, and have thought the direction of the several voluntary muscles, in order to perform the various motions of the body, to be an office which its faculties are by no means equal to*. But if these motions be not owing to the mind, from what cause, I pray, external or internal, do they proceed? They cannot be owing to the powers of the body alone; and it is in vain to attribute them to any LAW which it may be pretended the DEITY has established†; since a law can produce no effect of itself, and, without some agent to execute it, is only a mere name or empty sound: they must, therefore, be ascribed either to the immediate agency of the SUPREME BEING, or to that of some general inferior NATURE, which

* *Haller.* not. in *Boerhaav. Institut.* vol. iv. p. 588.

† *Id.* *ibid.*

which HE has constituted for this purpose, or to the energy of a particular active PRINCIPLE united with the body. The first two suppositions are indeed, possible but not at all probable, as is the last; whence it may be inferred, that not only the voluntary motions, of which we are immediately conscious, but those also which we do not advert to, proceed from that SENTIENT and INTELLIGENT PRINCIPLE with which the AUTHOR of nature has animated our bodies; whose powers and operations, it must be owned, are, in many instances, as much above our knowledge, as is the nature of its union with the body, or the manner of their reciprocal action upon each other.

Obj. IV. If the vital motions were owing to the mind, they should be under its dominion or controul; and we ought at any time to be able to suspend or vary these motions at pleasure.

Answer. α. IN all actions which are the result of reasoning and deliberation, man evi-

dently appears to be a FREE AGENT : for he has it in his power, after weighing all motives and circumstances, to prefer this or the other action, or to abstain from acting altogether. But there are actions, towards the performing of which we are in no ways determined by reason, and where the mind is not a free but a necessary agent. Of this kind are the involuntary motions of those muscles, whose fibres are affected by any considerable *stimuli*; for the application of external objects to their proper organs, does not more certainly or immediately excite corresponding ideas in the mind, than certain uneasy sensations produce consequent motions of the body. As we cannot, therefore, hinder ourselves from seeing every object which is painted on the bottom of the eye, nor from hearing every sound which affects the ear; so neither can the mind refrain from exerting its power of moving a muscle, whose sensible fibres are strongly affected by a *stimulus*. And as no body ever went about to deny that it was the mind which sees colours and hears sounds, because, whenever the external causes

causes exciting these, are applied to their proper organs, we can, by no effort of the will, prevent ourselves from seeing or hearing, nor can see and hear objects or sounds different from what these impressions naturally represent ; so it must be wholly unreasonable to pretend that the vital and other involuntary motions cannot arise from the energy of the mind, because the will has no immediate power over them.

AN action is denominated free, from the agent's having willed or chosen it, when he had a physical power of doing otherwise ; thus the action of swallowing poison is said to be free, when a person chuses it, and might have refrained from it ; but the convulsive motions of the stomach and diaphragm which soon ensue upon taking it, are strictly necessary ; since the mind cannot, by any effort or exertion of its power, prevent them ; being as certainly determined to move these parts violently, from the disagreeable sensation which the poison excites, as a stone is in falling to the ground, or a balance in inclining to the side where there is the greatest weight, from the principle

ciple of gravity. The only difference in these cases is, that in the first, the cause operates by means of a living sentient principle; and in the last, acts upon inert and lifeless matter.

As the actions which necessarily follow an irritation of our muscles, or any uneasy sensation in the body, are not performed by the mind, in consequence of any previous ratiocination, or from any views of their being immediately necessary, or conducive to the welfare of the body; so neither do they flow from custom or habit; since new-born children perform them as well as the oldest and most experienced man. Infants, as soon as they come into the world, perform the action of breathing, though quite unaccustomed to it before; they shut their eye-lids upon the approach of light, vomit when their stomach is oppressed, suck when hungry, sneeze, or cough, upon any irritation of the membrane of the nose or windpipe, and void their excrements and urine, when these excite an uneasy sensation in their intestines or bladder.

It has been said that in the “ beginning
“ of life the vital motions were altogether
“ voluntary; and, that it is only from use or
“ custom, that they have become so neces-
“ sary, as to make it impossible for us to
“ hinder their going on in their usual man-
“ ner*.” But although custom may en-
able us to perform some actions with sur-
prising facility and little or no attention,
yet it will not render the motions of muscles
absolutely involuntary, which were original-
ly voluntary.—There is no instance in the
human body of any muscle, whose motion
can be fairly proved to have been volun-
tary in the beginning of life, that has by
custom or habit become so far independ-
ent on the will, as to be in *no degree* under
its immediate controul. Thus, although
we cannot put in motion the muscles of one
of the eyes, without, at the same time,
moving the muscles of the other eye, in
that way which we have always been ac-
customed to do, yet we can move these
muscles

* Dr Porterfield's Treatise on the Eye, vol. ii.

muscles as slowly, or swiftly, as we please, or restrain their motions altogether: and the learned M. *de Haller* has well observed against the followers of *Stahl*, that the muscles of the eye-lids, and those which serve to erect the back, though they are almost constantly employed, except in time of sleep, nevertheless continue to be subject to the will *. Further, since the motion of every voluntary muscle in the body becomes, at once, altogether involuntary, when its fibres or nerves are irritated, there is surely no need of having recourse to *custom* or use, in order to account for our having no power over the motions of the heart and alimentary canal.

It remains, therefore, that the motions performed by us, in consequence of irritation, are owing to the original constitution of our frame, whence the soul or sentient principle, immediately and without any previous ratiocination, endeavours by all means and in the most effectual manner, to avoid or get rid of every disagreeable sensation conveyed

* Not. in *Boerhaave Institut. med.* vol. iv. p. 588.

veyed to it by whatever hurts or annoys the body.

WHEN the organ is not extremely sensible, or when the *stimulus* is very slight, or is applied to some distant part, and not immediately to that which is to be moved, we can, by an effort of the will, restrain those motions, which otherwise would follow; but if the nerves of the part be more delicate, and susceptible of the smallest impression; if the *stimulus* be stronger and applied immediately to the organ which is to be brought into action; then the motions which follow, are necessary, and cannot be controuled by the power of the will; because the mind is more strongly affected by the uneasy feeling excited by the irritation, than by any arguments or motives it can possibly present to itself: for, although we may, in some cases, be fully convinced that these motions tend to the destruction of our body, yet even this consideration does not enable us, either to lessen or put a stop to them *.—To illustrate this matter

* A subtle defender of the Stahlian doctrine has at last been obliged to acknowledge, that the vital and other involuntary motions

matter by a few examples.—In voiding the excrement and urine, the contraction of the abdominal muscles and diaphragm is usually in some measure voluntary, and can be restrained at pleasure, because the *stimulus* is not only slight, but applied to a distant part ; but in a violent *tenesmus* or stranguary the motion of these muscles becomes altogether necessary and convulsive, not because the mind is less concerned in this last case than before, but because the painful sensation compels it to act.—If the internal membrane of the wind-pipe be slightly irritated, we can restrain coughing ; but if the tickling be strong, we lose this power.—When
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motions of animals are *morally* necessary, although not *truly* or *physically* so †. But those actions which are only *morally* necessary, are so far voluntary as to entitle the agent either to praise or blame ; and they are attended with a consciousness of liberty : while, on the contrary, the motions of the heart and alimentary canal, as well as of such voluntary muscles as are strongly irritated, are no indications of the moral dispositions of the mind, nor are they attended with the least consciousness of their being free, or that we could have restrained them by the power of the will. As these motions, therefore, are most certainly not *voluntary* ; so neither can they, with any truth or propriety, be said to be only *morally* necessary.

† Dr Porterfield's Treatise on the Eye, vol. ii. p. 154.

the *tunica cornea*, or *conjunctiva* of the eye, is gently stimulated, we can, by an effort of the will, prevent the shutting of the *palpebrae*; but when any thing very acrid is applied to these parts, the eye-lids are moved necessarily.—Although the contraction of the pupil arises from the action of light upon the *retina*, and not upon the fibres of the *iris*; yet this motion is altogether involuntary, on account of the extreme sensibility of the irritated part.

The motions of the heart and alimentary canal are wholly necessary, because the nerves of these organs are endued with a *peculiar* sensibility, and the *stimulus* is immediately applied to them *. Nor can the

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* Some physicians of note have concluded the heart to be possessed only of a very small degree of sensibility, because brute animals, after their *thorax* is opened, shew no signs of new pain when their heart is wounded. But, unless the heart were endued with a more acute feeling than the skin and other parts that are hurt in opening the chest, the sufferings of those animals ought not to be sensibly increased by pricking or cutting their heart. Add to this, that, after the *thorax* is opened, and the heart laid bare, the animals, being in a dying state, have all their feelings much impaired.

Since

mind lessen the violent contractions of the heart in a fever, however conscious it may be

Since the sensibility of the medullary part of the brain has been inferred from the convulsive motions, occasioned by irritating it, may we not conclude, that the heart, whose motion is remarkably accelerated even by very gentle *stimuli*, is endued with no inferior degree of feeling? and this seems to be confirmed, by observing, that, the motion of the heart is often greatly quickened by a degree of acrimony in the blood imperceptible to our senses, and by the chyle, which is much less acrid than those aliments from which it is prepared, and which the stomach and intestines bear without any pain or remarkable increase of their peristaltic motion. I shall only add, that the internal surface of the heart, to which the returning venous blood is applied, appears from experiments *, to be much more sensible than its exterior part, which is covered with a continuation of the *pleura*, whence that fluid, which is a *stimulus* peculiarly adapted to the nerves of the heart †, must affect it more strongly, than sharper liquors applied to it outwardly.

The objection to the sensibility of the heart, drawn from its having been found much diseased after death, although the patients had complained of no *acute pain* within the *thorax*, is of very little force; for I have often met with inflammations, suppurations and mortifications in several of the abdominal *viscera*, nay, even in the intestines themselves; in the bodies of patients, who had, during their life, complained rather of an uneasiness than an acute pain within their belly: and practical physicians well know, that, according to the degree of the disease, and peculiar constitution of the patient, inflammatory as well as other disorders are attended with very different

* Aët. Gotting. vol. 1.

† See above p. 21, 22. & 56, 66,

be of the danger arising from too impetuous a motion of the blood ; because the heart being more strongly stimulated than usual by that fluid, the sentient principle, in order to expel the irritating cause, is necessarily excited

different degrees of pain. Nor is the instance, quoted from *Harvey*, of a young nobleman who felt no pain when his heart was touched, of any weight ; for, in this case, the heart was defended by a thick insensible fungous or callous covering * ; whence handling it, gently, neither occasioned any uneasy sensation nor disturbed its motion. And, indeed, as neither the membrane which lines the nose and *fauces*, nor the tongue, *glans penis* and intestines †, although among the most sensible parts of the body, are affected with any painful sensation when they are gently touched ; it is probable, that were the *pericardium*, or even the surface of the heart itself, in a sound state, to be touched with one's finger, no pain would be felt, but a different kind of sensation, which might perhaps disturb its regular motion, and occasion some degree of faintness.

The *stimuli*, which, in a natural state, excite the alternate motions of the heart and alimentary canal, do not affect these organs with any painful sensation, but with a slight titillation, which in *some* cases is as effectual to produce motion, or even more so than pain : Thus when the neck, the sides, or the soles of the feet are tickled, violent motions of the muscles of the head and trunk of the body or of the limbs ensue ; which however do not happen, when those parts are affected with an acute pain, by being pricked or cut with a sharp instrument.

* *Harvei de generat. animal. exercitat. lii.*

† See *Physiological Essays* edit. ii. p. 156.

excited to contract this muscle with proportionably greater force.—The motions of the inspiratory muscles can be accelerated, retarded, or altogether stopt, as often as we please; because the *stimulus* exciting them, is not immediately applied to their fibres or nerves but to the blood vessels of the lungs, which are not very sensible, and with which they have little or no connexion. However, as often as this *stimulus* is greatly increased, by the difficult passage of the blood thro' the lungs, and there is an immediate danger of suffocation, the motion of those muscles becomes more necessary, and almost ceases to be under the power of the will.—In a fever, when, from an obstruction or perverted motion of the fluids in the brain, or its membranes, the patient talks of seeing and hearing things which are neither present nor spoken, he may be readily convinced of his error, provided the *delirium* be of a slight kind; if otherwise, we endeavour in vain to correct his wrong judgment by reason or argument, since the disordered state of the brain makes a stronger impression upon the mind, than any arguments

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or external considerations whatever: yet acrid cataplasms applied to the soles of the feet, as they give great pain, and so make a remarkably strong impression on the *sem-sorium commune* will often lessen, and sometimes entirely remove such a *delirium*. But,

β. THE objection against the mind's producing the vital motions, drawn from their being involuntary, must appear extremely weak; since there are a variety of motions equally independent upon our will, which yet are certainly owing to the mind. Thus, as has been already observed, the contraction of the pupil from light, and the motions of the body from tickling, or the apprehension of it, undoubtedly flow from the mind, notwithstanding their being involuntary.—The shutting of the eye lids, when a blow is aimed at the eye, is another instance of a motion performed by the mind in spite of the will; for as the threatened blow does not, by any corporeal contact, affect the orbicular muscle of the *palpebræ*, its contraction must necessarily be deduced from the mind, moved to perform this action from the apprehension of something ready to hurt the eye:

eye: and if there are some who, by an effort of the will, can restrain this motion of their eye-lids, yet this does not proceed so much from the mind's making no attempt, in consequence of the apprehended danger, to close the *palpebræ*, as from the superior eye lids being kept up by a strong voluntary contraction of its *levator* muscle.

—We cannot, by an effort of the will, either command or restrain the erection of the *penis*; and yet it is evidently owing to the mind; for sudden fear, or any thing which fixes our attention strongly and all at once, makes this member quickly subside, though it be ever so fully erected. The titillation, therefore, of the *vesiculæ seminales* by the *sēmen*, lascivious thoughts, and other causes, only produce the erection of the *penis*, as they necessarily excite the mind to determine the blood in greater quantity into its cells*.—A shocking sight, or a disagreeable sound, will often, in an instant, excite a *tremor* or shivering over the whole body; which cannot be owing merely to the mechanical action of light upon the eye, or of sound

* Vid. Sect. vi. N^o 4. above.

found upon the ear ; since, when the external organs are unaffected by these things, their idea, recalled by the mind, can of itself produce a similar effect : this motion, therefore, though it be involuntary, and can neither be performed nor stopt at pleasure, must necessarily be owing to the mind or sentient principle.

IF, therefore, we have found various involuntary motions arising from the mind, it can be no proof against the vital motions flowing from the energy of the same principle, that they are involuntary : and if the motions of the voluntary muscles themselves become involuntary, as often as they are excited into action by *stimuli* applied to their fibres, or nerves, it can be no wonder that the motions of the heart and alimentary canal are necessary, and independent on the will, since these organs are perpetually exposed to the alternate action of a *stimulus*.

IF it be asked, why, when neither light nor sound affect the muscles of the *uvea* and internal ear, we cannot at pleasure move them ; or why we cannot at any time, by an effort of the will, immediately produce an erection

erection of the *penis*; it may be answered, that as mankind, by having their ears tied down when young, lose the power of moving them, though there seem to be muscles destined by nature for this purpose; so the mind, through disuse, may have lost its power of moving the above mentioned muscles at pleasure, even when they are not acted upon by a *stimulus*: or why may we not, for wise purposes, be so framed by the AUTHOR of nature, that the mind, while it can at pleasure contract the greatest part of our muscles; may have no power over others, whose motions are to be regulated only by certain sensations, since *these* will never fail to excite the sentient principle into action, when it is necessary or proper? whereas, if those motions were subject to the will, it is probable, that men, by a perverse effort of this, would in many cases greatly prejudice their health, or endanger their lives. And I imagine, that the mind's want of power over the motion of the heart; is not only owing to its being continually acted upon by a *stimulus**, but in part to

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* Sect. i. N^o 12. & 13. above.

an original constitution * ; and that tho' we should suppose that organ for a little while free from every degree of irritation, yet the mind, by an effort of the will, could not move it. Thus, notwithstanding the mind remains present with the body, and ready to actuate it in a *syncope* ; yet it can neither directly renew the heart's motion after it has ceased, nor communicate a stronger contraction to it when it is just going to fail: and there is no reason to think, that these animals which lie in a death-like state during the winter-season, have, when they begin to revive in the spring, any more power over the motion of their heart, than those in whom its motions continue without any such interruption from the beginning to the end of their lives.

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* By an original constitution, I here mean no more, than that we are so formed, that the mind, which can at pleasure move most of the muscles of the body, has, from the beginning of life, no power to move the heart and other involuntary muscles, unless when it is excited to do this by *stimuli* acting upon them, or upon some neighbouring part with which they have a peculiar sympathy.

We need not, therefore, with Mr *Lieutaud*, have recourse to any crossings or *entrelacements* of the nerves of the vital organs, or to their proceeding from different parts of the brain, in order to account for their not being subject to the power of the will*; especially since we see that the motions of the *uvula* and muscles of the internal ear, notwithstanding their nerves are destitute of the above conditions, are equally involuntary with those of the heart; that the muscles of the arm, whose nerves have these crossings, are, nevertheless, moved by us at pleasure; and that, in short, even the voluntary muscles, when affected by any remarkable *stimulus*, cease to be under the controul of the will†.

Obj. V. THE mind can only perceive distinctly one idea at once; and therefore must be incapable to attend to and govern all the vital and involuntary motions, which are so numerous‡.

Answer. THIS objection is chiefly levelled against the opinion which supposes the
vital

* *Essais anatomiq.* p. 702. & *Element. Physiol.* p. 72.

† See above, sect. i. N^o 12. & 13.

‡ *Haller.* not. in *Boerhaave institut. med.* p. 589.

vital motions to be regulated and carried on by the mind as a rational agent, and therefore does not much affect our theory : for whether the mind can distinctly apprehend more ideas than one at a time, or no, yet surely it can and does feel various sensations in different parts of the body at one and the same time ; and we know that it can move many of the voluntary muscles in the same instant. Why, therefore, may it not, in consequence of the perception of various *stimuli* affecting the different vital organs, move them alternately ?

BUT further, when *Mahomet Caratta*, the famous equilibrist, stood with one foot on the slack wire, tossing, with his hands, six or seven balls up into the air, and catching them again, was he not attentive to more than one thing at once ? In this case, the *equilibrium* of the body was to be preserved, the balls were to be taken out of his girdle, they were severally to be thrown up into the air, to be caught as they came down, and tossed up again ; and these motions, which followed each other with surprising quickness, were con-

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tinued for some considerable time. Any man can hear a sound and perceive a particular colour at the same time; and though ever so attentive to these, he will not fail, if a fly happens to run along his face, to drive it off with his hand, that he may avoid the tickling sensation which it excites. In like manner, how much soever the mind may be busied with its own thoughts, or the ideas of external objects; yet is it ever ready to perceive and feel the various *stimuli* which alternately affect the vital organs, and, in consequence of this, to continue their motions. Nor is there any need of an infinite wisdom in the mind, as some have objected, to enable it to carry on the several vital and other involuntary motions, with different and always varying degrees of force and quickness, according to the different circumstances of the body; since, in doing this, the mind has no particular wise ends in view; nor is it influenced by any rational motives, but merely by the *stimuli* affecting the several organs, *i. e.* it acts as a SENTIENT, and not as a RATIONAL principle. In the AUTHOR of nature,
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however, who has framed both the soul and body, and thus adapted them to each other, we ought, as upon many other accounts, so also upon this, to acknowledge a wisdom that is infinite and unsearchable!

IN contemplating the various motions of animals, we observe a striking analogy; a remarkable agreement in some things, and a disagreement in others.

1. SOME of the voluntary motions, by the force of custom and habit, come at length to be performed with little or no attention of mind; and, though we have full power to begin or stop them when we please, yet they become so far independent of the will, that we can only perform them in a certain way. Of this the uniform motions of the eyes are an example.

2. NEARLY a-kin to these are the mix'd motions, or those of a middle nature between the voluntary and involuntary; such as respiration, and the motions of the eyelids when any thing slightly irritates the

cornea. These agree with the motions from habit, in being often performed without consciousness; but in this they differ, *viz.* that the former proceed from a *stimulus*, and become altogether involuntary when this is increased; while the latter owe their beginning to an effort of the will, and are always subject to its controul.

3. THE involuntary and mix'd motions, agree, in general, in proceeding from a *stimulus*, and in being mostly performed without consciousness; but differ, in the latter's being partly, and the former not at all under the power of the will. Some of each of these motions never cease, but go on alternately through the whole of our lives; while others are only excited on certain occasions: among the former kind are the motions of the heart, lungs, and alimentary canal: of the latter are the contraction of the pupil, eye-lids, and muscles of the internal ear.

4. IN some of the involuntary motions, we are neither conscious of the *stimulus*, nor
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of the effort of the mind in consequence of it; as is the case with the motion of the heart, and the ordinary vermicular contraction of the stomach and intestines. In others, we are sensible of the irritation, or disagreeable perception exciting them, but not of any exertion of the mind's power: such are the convulsive contractions of the stomach, diaphragm, and abdominal muscles in vomiting, of the diaphragm in the hiccup, of the intestines in purging, and of the *acceleratores urinæ* in expelling the *semen*.

5. WITH respect to the mix'd motions: in those of the eye-lids, so far as they are of this kind, we are sensible of the irritation, or cause exciting them, though rarely so of any effort of the will.—In that of respiration, neither the *stimulus* affecting the lungs, nor the effort of the mind in consequence of this, are usually perceived; yet, as often as we please, we can suspend or vary this motion, as freely as those of the eye-lids.—In the motions of the diaphragm and abdominal muscles, in expelling the excrement and urine, which are also of the mix'd kind, we
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are perfectly sensible of the *stimulus*, and frequently of an exertion of the mind's power in consequence of it ; yet, when the irritation is very great, these motions become altogether convulsive and involuntary

6. FURTHER, it appears, that as in all the works of nature, there is a beautiful gradation, and a kind of link, as it were, betwixt each species of animals, the lowest of the immediately superior class, differing little from the highest in the next succeeding order ; so in the motions of animals something similar may be observed ; the mix'd motions, as they are called, and those from habit, being the link between the voluntary and involuntary motions.

Lastly, FROM what has been advanced in this and the preceeding sections, with a design to shew what concern the mind has in producing the vital and other involuntary motions, it clearly follows, that the human body ought not to be regarded (as it has too long been by many Physiologists) as a mechanical machine, so exquisitely formed,

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as, by the mere force of its construction, to be able to perform, and continue, the several vital motions * ; things far above the powers of mechanism ! But as a system, framed indeed with the greatest art and contrivance ; a system ! in which the peculiar structure of each part is not more to be admired than the wise and beautiful arrangement of the whole ; nevertheless, as a system whose motions are all owing to the active power, and energy, of an immaterial sentient principle to which it is united, and by which every part of it is enlivened and actuated.

IN accounting for the vital and other involuntary motions of animals, we have shewn, that they are all owing to irritation ; and have pointed out the particular *stimuli* applied to the several organs, and exciting them into action ; we have further shewn, that these *stimuli* can only produce their effects by the influence they have upon the mind or sentient principle. But what way the mind puts the muscles into motion ; what

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* See Heister's Dissert. de prestant. medicin. mechanic. p. 22. 25. 51. 69.

is the *material* cause in the brain, nerves, and muscular fibres, which it employs as its instrument for this purpose; what the intimate structure of a muscular fibre, or the precise manner in which the nervous influence acts upon it, when it produces its contraction: these are questions we have wholly avoided, being persuaded that whatever has been hitherto said on these subjects, is mere speculation; and that to offer any new conjectures on matters so greatly involved in darkness, and where we have neither *data* nor *phænomena* to support us, is to load a science already labouring under *hypotheses* with a new burden.

To complete our account of the spontaneous motions, it now only remains, that we inquire into the reasons why the vital motions continue in time of sleep, and why the muscles, or a few of their fibres, are often observed to move for some time after death or their separation from the body.

S E C T. XII.

Of the reason why the vital motions continue in time of sleep.

THE reason why the vital organs are continually agitated with alternate contractions, while the other muscles of involuntary motion are contracted on certain occasions only, may fully appear from what has been already offered ; for we have seen that the former are always exposed to the action of *stimuli*, the latter only at particular times. But since, during sleep, the organs of sense become less fit for receiving the impression of external objects, and the voluntary muscles are, in some measure, relaxed and remain inactive, it may be asked, why the vital motions do not at this time either cease altogether, or become remarkably languid ?

To say here, that the vital motions must therefore go on without being weakened or disturbed, because their organs are equally acted upon by their proper *stimuli*, both
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when we are awake and sleeping, would be an incompetent answer to this question ; for though the stimulating cause be granted to continue the same, yet if the organ's aptitude for motion be lessened, the effect must be the same, as though the *stimulus* were weakened or entirely wanting. The difficulty, therefore, which we are to endeavour to remove, is, why the vital organs should not, like the organs of sense and muscles of voluntary motion, be so far affected by sleep, as to become less fit or able to perform their usual functions?

SLEEP has been supposed to be owing to some change produced in that part of the body which Anatomists, distinguishing it from the *cerebellum*, call the BRAIN. And this opinion seems to have been rendered probable by some instances of people who, having lost part of their skull, were immediately seized with sleep, whenever their brain was gently pressed ; and by those experiments which shew, that, instead of sleep, death itself, or at least a *syncope*, is the effect of a like compression upon the *cerebellum*. If, therefore, it could be made appear, that
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the vital organs have their nerves chiefly from the *cerebellum*, and not from the brain, it might be presumed, that their motions continue in time of sleep, because the nerves of the *cerebellum* are not then affected like those of the brain.

Now there are many experiments of *Vieussens* *, *Ridley* †, and others, shewing, that respiration and the motion of the heart are quickly stopt upon wounding the *cerebellum*, but that wounds in the brain produce little or no change in these motions. On the other hand, several authors of great reputation and unquestioned veracity assure us, that, in their experiments, the vital motions continued for some considerable time after the *cerebellum* had been cut in pieces. However, it does not, by any means, appear from other experiments of these very authors, that wounding the brain or cutting it in pieces affected the vital motions more, or even so much, as the same treatment of the *cerebellum*. Are we then to conclude, from these experiments, that neither
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* Neuograph. lib 1. cap. 20.

† Anatomy of the brain, chap. 17.

the brain nor *cerebellum* are necessary to the motions of the vital organs? By the like kind of reasoning, it would seem, that the nerves also, and the influence they may have, are unnecessary in the producing of these motions, since that of the heart has been known to remain a considerable time after the intercostals and eight pair of nerves have been cut. Do these experiments, therefore, which prove too much, prove nothing at all? Far otherwise. The true inference seems rather to be this; That, since various experiments concur in shewing the *cerebellum* to be more concerned in the vital motions than the *cerebrum*, while none at all can be produced in proof of the *cerebrum* being more immediately necessary to these than the *cerebellum**, it follows,

* In the accurate Dr *Kaau*'s experiments, the vital motions continued in a dog, above eight hours after the medullary part of the brain was broken down into a pulp; but when the medullary substance of the *cerebellum* was treated in the same way, though they did not cease instantly yet they began to fail in a few minutes †. When the *cerebellum* was wounded, without

† Impet. faciens. N. 325.

follows, that the vital organs have their nerves, either wholly or principally, from the latter.

BUT though the *cerebellum* be the chief source of the vital nerves, yet its destruction does not put an immediate stop to the vital motions, for the same reason that cutting off the head, or tying the intercostal and eighth pair of nerves, does not produce this effect; *i. e.* because the branches from the spinal marrow which join the intercostals together with the spirits (if I may be allowed to call the influence of the brain by that name) remaining in the trunks of the nerves and fibres of the heart, are sufficient to keep up these motions for some time: in man, perhaps, only for a few pulsations, in young dogs or cats for several hours, and in a tortoise for several months; which last animal, not to mention other differences, has its spinal marrow remarkably large: nay, the motion of the hearts of many animals, after they are taken out of their bodies, affords

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out touching the *cerebrum*, the heart's motion failed sooner than when the brain alone was wounded *.

* Impet. faciens. N. 326.

us ocular demonstration that the nervous influence, lodged in the fibres of the heart and in the smaller filaments of the nerves, is sufficient to continue the motions of this muscle for some time, or to enable it to perform a great number of contractions. *

THE instances given us of animals, whose *cerebella*, upon opening them, were found scirrhus, corrupted, or otherwise diseased, avail no more, towards proving that the vital organs don't derive their nerves chiefly from this part, than do the histories of ossified and petrified brains, or of monsters born with no brain at all, towards making it a clear point that the brain and nerves are, in fact, not the source of sense and motion †.

BUT as it is now acknowledged, by the best anatomists, that the 5th pair of nerves proceeds

* The learned M. de *Haller* indeed, has concluded from the continuance of the heart's motion after its separation from the body, that it cannot be owing to the influence of the nerves; but this phenomenon does not warrant any such conclusion; and that the moving power of all our muscles, the heart not excepted, proceeds from the nerves I have clearly proved in my *Physiological Essays*, Edit. ii. appendix, pag. 245. &c.

† See Sect. 1. N^o 1. above.

proceeds from the *cerebellum*, which, however, is not distributed to the vital organs, but chiefly to the teguments of the head, and muscles of the face, whose motions are voluntary; it may be said, that allowing the nerves of the vital organs to come from the *cerebellum*, yet, why should not they suffer the same diminution of their vigour in time of sleep, as do those parts to which the fifth pair of nerves is distributed?

IN order to throw some light on this point, it may be of use to inquire, briefly, into the effects of sleep on the sentient and moving power of the nerves; for from this it will appear, whether or not the vital organs may reasonably be expected to continue their motions during sleep, even supposing them to be equally affected by it, as are the muscles of voluntary motion.

IN time of sleep, the *sensorium commune* remains, in a great measure, at rest, and consequently the usual exercise of the internal senses, and the voluntary motions, are suspended; but the nerves distributed to the several parts of the body do not lose either their sentient or moving power. It

must be acknowledged, however, that in time of sleep our feelings are less acute, than when we are awake ; and hence the same irritation in the *trachea* makes us cough less in the former, than in the latter state ; but, notwithstanding this, the nerves continue to be so sensible, that not only pricking any part of the body with a pin, but touching it gently with one's hand, or whispering softly into the ear, will break off sleep in many people. And as the feeling of the parts of the body, although it be impaired, is not suspended in time of sleep, so neither is their motion. Thus, altho' upon one's falling asleep, the muscles which support the head cease to act with their usual force, because the will does not exert its power in contracting them, in the same manner as when we are awake, yet neither these muscles nor those of the face are at that time deprived of the nervous power ; for, if a horse's hair be drawn along the face of a child when it is asleep, the muscles of the cheeks and mouth will be variously contracted ; and if this irritation be continued, the child will at length move
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its head, and perhaps turn its whole body. In like manner, uneasy feelings in time of sleep often make us move and toss about in bed ; and some people not only talk when asleep, but get up and walk from one room to another.

It appears, therefore, that in time of sleep there is no such diminution of the sentient or moving power of the nerves as to unfit the muscles of voluntary motion for action, provided the mind be excited, either by external *stimuli*, or by certain ideas produced in the *sensorium commune*, to put them in motion ; but when neither of these causes exist, it is no wonder if they remain at rest ; for the voluntary motions do not depend *solely* on the parts being in a fit state for action, but on an exertion of the power of the will ; which does not take place in time of sleep, unless when the *sensorium commune* is disturbed, or the nerves of some part of the body are affected by an unusual *stimulus*. And indeed, there is the greatest reason to believe, that were any of the voluntary muscles as constantly exposed to the action of an irritating cause as is the
heart,

heart, they would at all times, when we are asleep as well as awake, be agitated with alternate contractions. As a proof of this, many instances might be given of the voluntary muscles continuing to move in time of sleep. Thus, in asthmatic cases, the patients often perform inspiration, when asleep, partly by the action of those voluntary muscles which serve to raise the *scapulae* and superior parts of the *thorax*; and there have not been wanting various instances of other voluntary muscles being affected with convulsive motions which did not cease in time of sleep. I shall only mention one that was very remarkable.

A Girl of 8 years, for whom my advice was asked, was, without any known cause, seized with an alternate involuntary motion of the temporal and *masseter* muscles, which, altho' it was repeated about 140 times in a minute, and continued without intermission for fifteen days in time of sleep as well as when the patient was awake, yet was attended with no sense of pain, uneasiness or lassitude in those muscles.

Now,

Now, if an unusual irritation of the nerves or fibres of the temporal and *masseter* muscles could produce an alternate motion in them, much quicker than that of the heart in a sound state, and which continued for many days without any intermission; why may not the heart, which is at all times exposed to the alternate *stimulus* of the returning venous blood, continue its alternate motions through the whole of life, without either being wearied, or needing any time for repose? And this the rather, since it is not improbable, that, as the heart and intestines retain their power of motion, after they are separated from the body, longer than the other muscles, so their nerves may be framed in such manner, as to be better able than those of the voluntary muscles, to continue their motion uninterrupted, and without needing any intervals of rest.

I shall only add, that the account I have given of the continuance of the vital motions in time of sleep, is rendered still more probable, by observing, that, in a deep sleep, when the heart, as well as the other muscles and organs, loses a little of its sensibility,

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its motion becomes somewhat slower than when we are awake; and that *opium*, which is known to destroy, in a great measure, the sentient power of all the parts of the body, has been observed to render the motions of the heart remarkably slow in dogs, frogs, and other animals *.

As the minute structure and distinct uses of the brain and *cerebellum* are very little known, I am far from expecting, that what I have now advanced, concerning the cause of the continuance of the vital motions in time of sleep, will give every one full satisfaction, or be thought quite clear of all difficulties; I have only offered, in a few words, what seems to me most probable, being ready to change my opinion, as soon as farther experiments or observations shall lead

us

* The learned M. de Haller, who allows that *opium* weakens and at length destroys the peristaltic motion of the stomach and intestines, and the moving power of all the other muscles, trusting to two or three inaccurate experiments, which really prove nothing, has been led into so great an inconsistency, as to affirm that *opium* does not lessen the irritability of the heart, or render its motion slower or more languid. A mistake, which has been sufficiently refuted in the *appendix* to the 2. edition of my *Physiological Essays* pag. 284—296.

us to a better and more consistent account of this matter. *Sequimur probabiliora; nec ultra quam id quod verisimile occurrit progredi possumus, et refellere sine pertinacia, et refelli sine iracundia, parati sumus* *.

S E C T. XIII.

Of the difference between respiration and the motion of the heart in sleeping and waking persons.

ALTHOUGH the vital motions continue without any interruption in time of sleep, yet as they suffer some change at that time, *i. e.* become then, somewhat fuller, slower, and more equable than when we are awake, it may be worth while to inquire into the reason of this *phenomenon*.

IT has been shewn, that as the dilatation of the ventricles of the heart, is owing to the force of the reflux venous blood; so their contraction is produced, by the same blood

* CICERON. disput. Tusculan. lib. 2.

blood acting upon them as a *stimulus* *: and that the heart can only be affected by *stimuli*, in so far as it is a sentient organ, *i. e.* endued with feeling †. Whence it must follow, that the slowness of the pulse in sleep, and indeed in every other case, can only arise from one or more of the following general causes. *viz.* 1. A diminution of the stimulating quality of the blood. 2. Its slower return to the heart; or, 3. A less degree of sensibility or aptitude for motion in the heart itself.

I. WHEN one has eat or drunk a great deal before sleep, his pulse will be, not slow, but quick and full; because the stimulating power of the blood is increased, by a large quantity of chyle received into it; at the same time that the heart, by its sympathy with the stomach, is often rendered more irritable. Much the same thing may happen from sleeping in too hot an air, or under too great a weight of cloaths: for we know, that heat quickens the circulation of the

* See above, sect. iii. and iv.

† See above, sect. x, also pag. 300. &c.

the fluids in all animals. On the other hand, when one has fasted long before sleep, and lies very cool, his pulse will, in time of it, be unusually flow.

BUT when the blood is neither loaded with new chyle, nor become acrid through the want of it; neither too much heated by cloaths or the external air, nor too cool, thro' want of proper covering; its stimulating quality will neither be augmented nor diminished by sleep; but will continue the same as in a person who is asleep in the same circumstances. It remains therefore, that the slowness of the heart's motion in time of sleep, be owing, either to the slower return of the venous blood to it, or to some diminution of its sensibility.

II. IT is well known, that the affections of the mind disturb the motion of the heart; that the pulse is quicker when we sit or stand than when we lye; and that the action of the muscles of voluntary motion, not only promotes the return of the blood to the heart, but determines it thither, with much greater force than usual. In sleep therefore, where the horizontal posture of

the body, the quiescence of the voluntary muscles, and compofure of the mind, all concur to render the return of the venous blood to the heart, more equable and flow, the contraction of this organ must be renewed at greater intervals, and with more regularity, than when we are awake, and the circulation is quickened or disturbed by some, or all, of the above mentioned causes.

BUT, if no farther circumstance, tending to retard the heart's motion, were found in sleep, the pulse should be equally flow and full in a waking person lying at rest in a horizontal posture, and whose mind is composed, as in the same person in time of sleep; which, however, does not seem to be entirely the case: for tho' the difference may be small, and there may be many causes which may render it difficult, by observation, to determine that difference with any degree of certainty; yet the remarkable slowness and fulness of the pulse in the deep sleep, accompanying an appoplexy or occasioned by *opium*, makes it highly probable, that even in the much gentler sleep of persons in health, the pulse is somewhat slower and
fuller,

fuller, than it would be, merely from the compofure of mind, horizontal pofition of the body, and quiefcence of the mufcles of voluntary motion. Let us therefore fee, whether the flownefs and fulnefs of the heart's motion in time of fleep, may not be, in part, owing to fome diminution of the fenfibility of this organ.

III. IN time of fleep, as the exercife of the feveral fenfes, is either fufpended or much impaired ; fo the fenfibility or feeling, with which the organs of the body are more or lefs endued, feems to be rendered lefs acute. Thus we feel ourfelves affected with a kind of *ftupor*, when we are juft falling afleep, and are then infenfible of leffer *ftimuli*. The thin rheum, which, by irritating the wind-pipe, keeps us almoft perpetually coughing when awake, gives us little or no difturbance in fleep: any unufual *ftimulus* in the inteflines is alfo lefs perceived then ; and hence it is, that a dofe of any purgative taken at night, is much longer before it operates, than when it is fwallowed in the morning. If the heart therefore, like the other organs of the body, be-

comes

comes less sensible or irritable in time of sleep, it will not be so quickly excited into contraction as usual, by the venous blood rushing into its cavities; and hence its contractions will not only be more slowly repeated, but the pulse will be full, because the ventricles do not contract, till they are much distended with blood. This will still further appear, if we consider how remarkably slow and full the pulse is, in an appoplexy, where the sensibility of all the parts and their aptitude for motion, are much more impaired than in common sleep: and how *opium*, which occasions sleep, and lessens the sense of feeling every where thro' the body, when given in a large dose, renders the pulse uncommonly slow and full.

Does not the slower digestion of the aliment in time of sleep, proceed, partly, from the peristaltic motion of the stomach and guts being then repeated after longer intervals? In dogs who have got a large dose of *opium*, this motion is very much lessened or totally suspended, the food last received into the stomach remains there indigested, the bowels are more than usually empty, and
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the lacteal vessels invisible *. In sleep, therefore, not only the heart but the stomach and intestines also, become less sensible of the *stimuli* usually affecting them, and consequently repeat their contractions more slowly.

De Gorter, differing from *Boerhaave* and other authors, thinks, that the pulse must be, not fuller, but softer in time of sleep, because the circulation of the blood is allowed, then, to proceed more slowly than when we are awake †. But, from what has been said, it appears, that the fulness of the pulse in sleep, is not owing to the quicker circulation of the blood, but to a less degree of sensibility in the heart, whereby its ventricles are not excited into contraction, till they have been more fully dilated, than usual, by the returning blood. It is, however, to be observed, that the fulness of the pulse in sleep, may be owing partly, to the fluids passing, with greater difficulty, thro' the very small lateral arteries, and the secretory tubes

* KAAU impet. faciens HIPPOCRAT. dictum, No 434. 535.

† *De Gorter*, Exercitat. de somno et vigilia, § xl.

tubes of the glands *. For we know that the fulness or softness of the pulse does not depend, solely, upon the quantity of blood thrown out by the left ventricle of the heart, but also upon the more or less difficult passage of this fluid thro' the extreme arteries; since, in proportion as these are obstructed or open, a greater or less resistance will be opposed to the blood projected by the heart.

AFTER what has been said of the slowness of the heart's motion in sleep, it will be easy to shew why respiration should be performed, then, at greater intervals.

THE cause exciting the alternate contraction of the inspiratory muscles, is an uneasy sensation in the lungs, occasioned by the blood pushed into their vessels by the right ventricle of the heart †. If then less blood is sent, in a given time, into the lungs, in sleep, than when we are awake; the necessity of new supplies of fresh air will be lessened, and consequently inspiration will be performed at greater intervals.

FURTHER

* BOERHAAVE Institut. med. § 597.

† See Sect. viii. above.

FURTHER, as in time of sleep, the sensibility of the lungs, like that of the heart and guts, must be somewhat impaired, respiration must also, on this account, be performed more slowly; for the inspiratory muscles will not be excited into action till a greater degree of irritation, than usual, be occasioned by the blood accumulated in the pulmonary vessels. And, to this it is owing, that respiration is not only slower but somewhat deeper in time of sleep, than in a waking person at rest in a horizontal position.

IN comatous and appoplectic cases, where all the feelings of the body are much more impaired than in ordinary sleep, respiration is not only much slower and deeper than usual, but, sometimes, after expiration is finished, a pause of 15, 20, 30, or more seconds will intervene, before a new inspiration is begun. Much the same thing happens to animals who have swallowed too great a quantity of *opium* *.

Now, if it be reasonable to ascribe the slow, deep and interrupted breathing, in such

* See above pag. 216.

such cases, to the insensibility which attends those diseases of the head ; and which *opium* never fails to produce, when taken too liberally ; are we not hence led to conclude, the less remarkable change of breathing which happens in sleep, to be owing, partly, to the sense of feeling in the lungs, being then somewhat diminished, tho' in a much less degree than in those morbid cases?

To conclude with summing up what has been said in a few words, in ordinary sleep the sensibility of the heart and lungs suffer so small a diminution, that their motions will be very little more affected by it, than they would be from the horizontal position and rest of the body, and composure of mind attending it. In the deeper sleep, which succeeds great fatigue, the motions of the heart and lungs will be more observably altered. And, in the most profound sleep, occasioned by *opium* or a morbid state of the brain, where a general insensibility prevails over the whole body ; the pulse will become much more remarkably slow and full, and respiration slower and deeper.

S E C T. XIV.

Of the motions observed in the muscles of animals after death, or their separation from the body.

SINCE the hearts of many animals continue their alternate contractions for some time after they are taken out of their bodies; and as this is a circumstance which possibly may be mistaken for an unanswerable objection to the account we have given of the vital motions, * we shall here inquire, C c c particularly,

* Constat vero piscium plurimos, nec non insecta et alia quædam animalcula motûs sui aut vitæ admodum esse tencia, adeo ut in partes quoque dissecta se aliquamdiu adhuc motitent, imprimis, si adhibito stimulo insuper laceasantur. Quo ipso, luce meridiana clariùs apparet motus istos sine sensu edi: quis enim animam sentientem dividi aut sectione multiplicari posse existimet? *Peyeri Parerg. Anatom. vii. p. 200.*

“ Sed manifesto falsum est motus omnes ab anima oriri,
 “ et absque ea materiem fore immobilem segnemque massam.
 “ Nam vis contractilis ad stimulum quemcunque, ad quam
 “ motus cordis, intestinorum, et foret omnis motus in ho-
 “ mine pertinet, ne requirit quidem animæ præsentiam,
 “ superest in cadavere, suscitatur mechanicis causis, calore,
 “ flatu; neque deserit fibram, quamdiu nondum refrigerata ri-
 “ guit,

particularly, into the nature and cause of those motions which are so frequently seen in the muscles of animals after death, or their separation from the body;—and we flatter ourselves much, or it will hence appear, that instead of being inconsistent with our theory, they serve rather to illustrate and confirm it.

SEVERAL authors (some of them indeed of great character) have ascribed the motions of the heart after death, or its separation from the body, to some peculiar property, not found in the other muscles, wherewith they suppose it to be endued*: but with what reason, will appear from the

“guit, etsi dudum animam abegerit destructio cerebri cordis-
 “que, etsi, ex ipso corpore revulsus musculus, ab omni ima-
 “ginabili animæ sede separatus sit.” *Haller. Prim. lin. Physiolog. N° 562.*

* *Galen* imagined that motion was as natural to the heart as rest to the other muscles: and in his *Administratio anatom.* lib. vii cap. 8. he concludes, from the heart's continuing to move after it is taken out of the *thorax*, that its motions do not depend upon the nerves or any influence proceeding from them. See also *Van Swieten* comment. in aphor. *Boerhaave*, vol. 1. p. 2. & 3. And *I. G. H.* comment. in *Boerh. Instit. med.* vol. 5. p. 101. 104.

the following experiments and observations.

1. AN eel, which I dissected, moved the muscles of its body with great force, for more than half an hour after the removal of its heart and the other *viscera*; and, though I had not leisure to observe them, I doubt not but these motions continued a much longer time; for Dr *Harvey* has informed us, that not only the heart, but also the flesh of eels continues to move after being cut in pieces.

2. I have often observed a frog turning from its back to its belly, and leaping about for an hour after the heart and other *viscera* were cut out; and when its muscles were at rest, they have been brought into convulsive contractions, by pricking them with a pin or a penknife: nay, a frog's limbs seldom fail to move for some time after they are separated from its body.

3. A tremulous motion has been observed in the muscles upon the *sternum* for a quarter

quarter of an hour after it was cut out of the body ; and, when it had ceased, it was renewed by pricking the fibres of these muscles with the point of a knife*. The like tremulous motions have continued for an hour in the muscle of an ox separated from its body immediately after it had been killed, and, upon their ceasing, have been recalled, by pricking its fibres with a sharp instrument †.

4. IN a young pigeon, which I killed by separating its head from the *vertebræ* of the neck, the divided muscles of the left side of the *thorax* (upon which some of the blood thrown out of the heart had been spilt) were agitated with alternate contractions for about ten minutes. These contractions were very quickly repeated at first, but, like those of the heart, became much slower before they stopt altogether.

WERE not the alternate contractions of these muscles more remarkable, and of longer continuance, on account of the *stimulus* of

* *Swencke Hæmatolog.* p. 28.

† *Ibid.*

of the blood which was spilt on them? This seems not at all improbable, since, as has been observed above *, the motions of the *vena cava* continue longer than those of the heart, because it is longer supplied with blood. Besides, the alternate contractions which happened to the muscles of the *thorax* in other pigeons which I opened, and where no blood was spilt, were much less remarkable, and lasted but a very short time.

5. *Swammerdam* tells us, that, in dissecting animals alive, he observed contractions, not only in every muscle separated from the body, but also in every muscular fibre †. And the same kind of motion has been remarked in the muscular fibres of men, which had been cut away in the extirpation of tumors.

6. THE vermicular motion of the intestines remains for a considerable time after they are taken out of the body.

α HENCE

* Sect. vi. N^o 3.

† Tractat. de respirat. cap. 7. p. 67.

α HENCE it appears, that all the muscles of living animals, whether they be of the voluntary or involuntary kind, are agitated with alternate contractions, after being separated from their bodies; and, consequently, that the vibrations performed by the hearts of animals, after they are cut out of the *thorax*, bespeak not any latent power peculiar to the fibres of that organ, or which they do not share in common with those of every other muscle.

β If the voluntary muscles, which in a healthful state remain at rest when the will interposes not to the contrary, are alternately contracted and relaxed, as well as the heart, when they are separated from the body; it cannot be concluded, that, because the heart beats after such separation, it must therefore move also while in the body: on the contrary, it follows, that the alternate motions of the heart in living animals must be owing to its being acted upon by some particular cause, which does not affect the voluntary muscles.

7. THE heart of an eel, which I cut out of its body, and divided into two parts, continued its vibrations above twenty minutes.

8. WHEN the heart of an eel inclosed in an exhausted receiver, after beating about an hour, had become very languid, and almost ceased from motion, Mr *Boyle* renewed its pulsations, by breathing on that part of the glass where it lay *

9. I have observed the hearts of frogs beat 12, 15, 18, or 30 minutes and more, after being separated from their bodies; and when their motions began to languish, or were just about to cease, they were increased or renewed, by heat, or pricking them with a pin.

10. THE hearts of frogs, which, when first separated from their bodies, beat about sixty times in a minute, performed from betwixt 90 and 100 pulsations in the same time, when exposed a little to the heat of the fire; but, after being removed from it, their vibrations became gradually slower and slower,
till

* Philosophic. Transact. abridg'd, vol. ii. p. 222.

till they were no quicker than at first. While warmth thus increases and renews the motion of the heart, even in those animals whose blood is cold, too great heat destroys it both in hot and cold animals, by producing such a change in the nerves, muscular fibres, and their fluids, as renders them unfit for motion. Hence the heart of a pigeon or frog immediately loses its motion when immersed in boiling water.

11. THE hearts of vipers continue their alternate motions for several hours after they are severed from their bodies *.

12. A viper's heart, which beat only 25 times in a minute, when Dr *Langrish* first took it from its body, was, by the warmth of his hand, soon made to perform 48 vibrations in that time; and, being afterwards put in water a degree or two warmer than human blood, it repeated its pulsations 87 times in a minute †.

13. UPON

* *Boyle's* Usefulness of Experimental Philosophy, part 2. p. 16.

† *Cronean Lectures* on muscular motion, N^o 150.

13. UPON stretching a cock's neck so as to separate the head from the *vertebræ* of the neck, several violent convulsions ensued, and in less than five minutes he seemed to be quite dead. At this time laying the *thorax* open, I observed the heart performing its alternate motions, but much more faintly than that of a frog or eel when separated from the body. Three minutes after, when the heart's motion was become yet weaker, I cut it out of the body, and found its vessels and cavities had been filled with blood; which was no sooner evacuated, than the tremulous motions of this organ ceased; nor could they be recalled by breathing upon it, or pricking it in several places with a pin; but, by touching it two or three times with a red hot iron, a vibrating contraction was observed, which scarcely lasted for a second.

14. THE heart of a chick taken out of the shell, beat an hour after its head and breast-bone were clipp'd away with a pair of scissars, and the auricle retained its motion some time after the heart. The mo-

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tion

tion of the other parts seemed only to survive the loss of the head for a few moments. The heart's motion, when about to cease, was frequently renewed by pricking it with a pin. In another chick, the heart was kept beating, by the influence of warmth, above two hours after its head was cut off*.

15. I laid open the *thorax* of a young pigeon, four minutes after separating its head from the *vertebræ* of the neck, and found the heart, with its right auricle, which was greatly distended with blood, without any motion. I let a few drops of warm *saliva* fall from my mouth on the heart; upon which its right auricle began to move, and continued repeating its alternate contractions with remarkable vigour and quickness for three minutes, when they became gradually both weaker and slower. At eleven minutes from the beginning of the experiment, the motions of the auricle were still slower, but were quickened somewhat by pricking it with a pin. After eighteen minutes, the contractions of the auricle were much

* Boyle's Usefulness of Experimental Philosophy, part 2. p. 15. & 16.

much more feeble, and not repeated till after 7, 8 or 9 beats of my pulse; whereas, at first, they succeeded each other much more quickly than the vibrations of my heart. Before the twentieth minute was expired, the motions of the auricle ceased entirely; but were so far renewed afterwards, by filling the *thorax* with water of the same warmth with the human blood, as to last about two minutes. During all this time, no motion was observed in the body of the heart; nor were its fibres excited into contraction by pricking them with a pin, seven minutes after the *thorax* was opened.

16. I opened the *thorax* of another pigeon, three minutes after I had pulled off its head, and made a ligature about its neck: the right auricle, with part of the *vena cava inferior* adjoining to it, still continued to beat, but the body of the heart was at rest: some time after, when the motions of this auricle were about to cease, they were renewed with their former vigour by drawing asunder the sides of the divided *thorax*, and consequently stretching the great vessels leading
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ing to the heart. When the motions of the auricle were become very languid and slow, the *vena cava inferior* made several contractions before the auricle contracted once; and it continued to palpitate for some time after the auricle had ceased from motion altogether.

17. IMMEDIATELY after separating from the *vertebræ* of the neck the head of a pigeon somewhat younger than either of the two former, I laid open the *thorax*, and found the heart beating pretty strongly, and at every *systole* throwing out the blood with a considerable force by a wound which I had accidentally made in it. When after a few contractions, its motion had become much more feeble and irregular, it was made to recover its vigour and propel the blood through the wound as before, by drawing the divided *thorax* a little asunder. Sometime after this, when the heart was become much more languid, its contractions were renewed with double force as often as I raised the point of it with my finger. About six or seven minutes after opening
the

the *thorax*, the motions of the heart could be perceived only in its right auricle and *apex*, but were by far most remarkable in the former. In three minutes more, when no motion could be seen in the body of the heart, this auricle still continued to vibrate, and its motions were very sensibly quickened by raising the point of the heart, and of consequence stretching the great vessels adjoining to its base. At this time a few weak palpitations were excited in the heart by dividing it with a sharp knife.

18. SOME young Gentleman having hanged a cat till she was quite dead, opened the *thorax*, and observed only a tremulous motion in the heart which soon ceased, but was renewed by pricking it with a sharp instrument; after this, by squeezing the cardiac nerves downwards, or otherwise irritating them, the heart was made to perform two or three pulsations; which it continued to do for a considerable time, whenever the cardiac nerves were thus stimulated.

19. THE heart of a cat, which had been dead for four hours, was excited into alternate

ternate contractions, by blowing warm air into its cavities through a tube fixed in the *receptaculum chyli* *.

20. THE motion of the heart was renewed, in the same manner, by *Brunnerus*, in a dog which had been a good while dead †.

21. EVEN in man, the heart retains a power of motion for some little time after its separation from the body; as appears particularly from the well known story of Lord *Verulam* concerning a malefactor, whose heart, having been cut out of his body, and thrown immediately into fire, leapt several times upwards to a considerable height ‡.

22. IT is observable, that, after the convulsions which animals suffer at the time of death have ceased, their muscles remain at rest, unless they are stretched, cut, exposed to the air, or otherwise stimulated.

FROM

* *Weffer. histor. cicut. aquat. p. 89.*

† Experiment. circa Pancreas, p. 21.

‡ History of life and death, sect. ix. N^o 31.

FROM the above experiments it appears,

α THAT the separated hearts of some animals, vibrate more strongly, and for a much longer time, than those of others. N^o 9. 11. 13.

β THAT animals of the amphibious kind, which have either no lungs or very imperfect ones, which bear the air-pump long, and whose blood is cold, as well as languid in its motion, shew signs of life, not only in their hearts, but also in their other members, for a much longer time after they are separated from their bodies, than animals which have more perfect lungs, hotter blood, and a quicker pulse. N^o 1. 2. 4. 14.

THOSE animals whose parts preserve motion and appearances of life longest after being separated from their bodies, seem to have both their fluids and solids a good deal different from those of other animals : their blood is not only colder, but perhaps more viscid and less dissipable ; and their fibres are so constituted, that constant supplies of this fluid from the heart, are not necessary to keep them in due order for motion ;
while

while their nerves, after their communication with the brain has been cut off, preserve their powers much longer than in man and the more perfect animals: thus frogs, eels, vipers and tortoises live and move several hours after their heart is cut out; and the various parts of their bodies continue to move for a great while after all communication between them and the brain is cut off.

γ THAT, *cæteris paribus*, the heart preserves its motions longer in young animals, after its communication with the brain is intercepted, than in older ones. N° 13. 15. 16. compared 14. 17.

δ THAT, *cæteris paribus*, the hearts of those animals which continue to beat longest, after being separated from their bodies, perform their vibrations at the greatest intervals. N° 9. 10. compared with 11. 12. The reason of this is easily understood; since, as has been just now observed, in those animals, whose hearts beat longest after separation from their bodies, the blood is coldest and its circulation most languid.

THAT

THAT the motions of the heart, after death or separation from the body, are generally more conspicuous, and last longer, than those of the other muscles. No 14.

§ THAT the right auricle continues to move, after the heart appears quite dead, No 14.—17.

ⁱ THAT the *vena cava* and *sinus venosus dexter* preserve their motions still longer than the right auricle. No 16.

θ THAT the motions of the heart and other muscles, when separated from the body, are not only at all times increased, but even renewed, when they are just at an end, by heat, wounds stretching their fibres, or any thing else that can gently irritate them. No 2. 3. 4. 8. 9. 10. 12.—17.

ι THAT, after the heart has entirely, and for a considerable time, ceased to move in dead animals, it may be excited into action by stretching or stimulating its fibres or nerves, No 18. 19. 20.

κ THAT as in living animals the voluntary muscles are not convulsed, except when some *stimulus* is applied to them; so in animals newly dead, no convulsive contractions

E e e

happen,

happen, provided the skin be not so cut as to lay them bare, and expose their fibres to some kind of irritation. N^o 22.

^ WHENCE it follows, that the vibrating contractions of the muscles of animals after death, or their separation from the body, cannot be owing to any innate power, whereby, independent of all external causes, they move themselves alternately, but must be ascribed to the action of a *stimulus* of one kind or other upon their fibres.

WHEN the heart is taken out of the body in animals newly dead, the cutting alone must be a very remarkable *stimulus*, and therefore, must not only excite or increase its motions, but also make them continue for a considerable time. When the *thorax* and *pericardium* are only laid open, the vibrations of the heart will be increased and continued by dissecting and stretching these parts with which it is nearly connected, (N^o 16. 17.) and even by the external air acting as a *stimulus* upon its sensible nerves; for the particles of this fluid are never at rest, but agitated with incessant vibrations. This undulatory motion of the air is so remarkable,

markable, as to be observed by the assistance of good telescopes, and is clearly enough seen in the constant whirl of dusty atoms, and other light substances, perceived in the stillest room, where-ever the sun beams play.

THE motions of the heart; therefore, in animals newly dead, or after it is separated from the body, are owing to the *stimulus* of the blood remaining in its cavities, to the contact of the external air, or to the irritation which is communicated to it, by stretching or cutting its own fibres, or those of such parts as happen to be immediately connected with it.

IN a *syncope*, and in animals newly dead, the intestines continue their peristaltic motion after the heart has ceased to vibrate, which cannot be ascribed to their being more fitted for motion, since the heart, when separated from the body or otherwise irritated, moves more remarkably than they; but is owing to their being acted upon by their usual *stimuli*, even after the heart is deprived of that regular and alternate supply of venous blood which was wont to keep
up

up its motion : as therefore the bile, air, and aliment, remain in the intestines equally after death as before it, they will continue to excite the fibres of the various portions of this canal into alternate contractions, till at length they become quite insensible and rigid with cold.

MR *Boyle* tells us that the heart of an eel being placed in a small receiver, became very turgid when he exhausted the air, and beat as manifestly, and more swiftly than it had done before *; the reason of which *phenomenon* is abundantly evident from what has been said; since the stretching of the fibres of the heart thus swelled, must have had the same effect in quickening its vibrations, as any other *stimulus*.

DR *Harvey* observed, that in time of incubation, the chick's heart, whose motion languished, and at length ceased in the cold air, quickly recovered its vigour by heat, and contracted with greater force and frequency as often as it was touched with the point of a needle or any thing else that
could

* Philosoph. Transact. abridged, vol. 2. p. 222.

could irritate it * ; from which it follows that the same causes excite the motion of the heart in living animals and in those newly dead, in the body and out of it.

THE conclusion to be drawn from what has been said is, that there remains in the muscles of animals and their nerves, for some time after death or their separation from the body, the immediate cause of motion, which may be excited into action, as in living animals, by any *stimulus* or irritation. How or by what means this happens, shall be the subject of our next inquiry.

SOME have ascribed the motion of the heart out of the body, and consequently of other muscles separated from it, to the spirits remaining in their nerves, which, by the capillary attraction of these tubes, or the cold contracting them, continue for some time to be derived into the muscular fibres. But from such an equable derivation of the spirits, it will be difficult to account for the regular alternate contractions and relaxations of these muscles, or for their
being

* De generat. animal. exercitat. xvii.

being excited and renewed by *stimuli* of very different kinds.

OTHERS have been inclined to deduce the vibrations of the heart, when out of the body, from the elastic power of its fibres *, or of the spirits lodged in them † ; which are excited into oscillations by any impulse or irritation, and which, observing the same laws with other elastic bodies, must persist in these tremulous motions for a considerable time.

But if the motions of the heart, or other separated muscles of animals, were owing to any such cause, how could their vibrations be excited by bringing a red hot iron near them, after the impulse and tearing of a pin or the point of a knife had ceased to have any effect? (N^o 13.) Will warm water heighten and increase the elastic powers of any body? Does it not rather weaken and relax animal fibres? And how can acrid liquors, which communicate no impulse
at

* *Hoffman. system. med. tom. 1. lib. 1. sect. 1. cap. 3. N^o xviii.*

† *Lancisi de corde, prop. 58. Licutaud element. Physiolog. p. 71, 72. Senac traité du coeur, vol. i. p. 434. & 452.*

at all, excite vibrations in an elastic machine?

FURTHER, as the times of the vibrations of a *pendulum* in a cycloid would be exactly equal, however unequal the arches which the body describes may, be were it not for the small inequality that the resistance of their air necessarily occasions; so the vibrations of a *pendulum* in a small arch of a circle, which coincides with the cycloid, and the oscillations of elastic bodies, would follow one another at equal intervals of time, were it not for the air, which, as it resists a great vibration of a *pendulum* or elastic body more than a small one, must consequently retard it more; whence, strictly speaking, the first and greater vibrations of such bodies must follow each other more slowly than the last and smaller ones. But as this difference is too inconsiderable, especially in small vibrations, to be perceived by us; so, in a physical sense, we may be allowed to say, that the vibrations excited in elastic bodies by any external cause, though they be always decreasing in greatness and force, are yet performed
from

from first to last at equal intervals of time. Let us now see how far the separated hearts of animals observe the same law, in their motions.

23. THE hearts of frogs, when their *thorax* is first laid open, generally beat about sixty times in a minute; but after they are separated from the body, and have been in motion for some time, their vibrations begin to grow sensibly slower, so as only to be renewed after an interval of 2 or 3 seconds; and, a little before their motion ceases altogether, I have counted 7, 10, 14, 15, 16, or more beats of my pulse * between their pulsations, each succeeding pulsation following the former not till after a longer pause, which at last ended in a final stop. In the separated heart of a frog (into whose stomach I had forced, about an hour and a half before opening it, a small quantity of *opium* dissolved in water) I observed the intervals between the six last pulsations to increase nearly in the following proportion, 11, 13, 16, 19, 23, 30; which numbers denote

* The motion of my pulse was at the rate of 75 in a minute.

denote how many beats of my pulse intervened betwixt each of these vibrations. From which it appears, that, before the last pulsation of this frog's heart, there was a pause of 24 seconds.

WHAT is here said of the motions of the separated hearts of frogs becoming remarkably slower as they grow weaker, is also true of the hearts of eels; and holds not only in the pulsations of the right auricle of a pigeon's heart, which remained in the body after death, (N^o 15.), but in the contractions also of the muscles of its *thorax* after dissection, N^o 4.

SINCE, then, the motions of the hearts of animals after death, or after they are separated from their bodies, decrease gradually in quickness, as well as in strength, and become, at last, so slow, that, before they cease altogether, the heart reposes itself, as it were, for a considerable time, and, after appearing to have been quite dead, performs yet another contraction slowly, and with much seeming difficulty; it evidently follows, that they are regulated according to laws wholly differ-

ent from those of elastic bodies ; and that every attempt to account for these motions, from elastic powers of whatever kind, supposed to reside in the heart, must be vain and fruitless ; and can only serve to shew, that the authors or supporters of such opinion were either ignorant of the nature of elastic vibrations, or unacquainted with the *phænomena* recited above, (N^o 23.)

WE may also see, from what has been said, with how little reason the motion of the heart, after its separation from the body, has been ascribed to the alternate action of its distending fluids and contracting solids ; and compared to the *folliculus*, which being let fall from a height, does not lie still upon the ground, but is immediately thrown off from it, and continues to rise and fall alternately for some time *.

IT appears, from the experiments already recited, compared with N^o 8. 9. 10. and 11. of Sect. I. and with what has been advanced Sect. X. p. 269.—271. and 284.—287. that the motions of the heart and other muscles after death, and when separated

* *Santorini de structura et motu fibræ, sect. 73.*

ted from the body, are owing to a *stimulus*; that where no *stimulus* is applied, they either happen not at all, or soon cease; that, when failing, they are excited a-new by any irritation; and that, in the laws they observe, and the *phenomena* they exhibit, they agree exactly with the motions which *stimuli* excite in the muscles of living animals. But we have fully shewn, in Sect. X. that the contractions of the muscles of living animals, arising from any thing that tears, stretches, or otherwise irritates their fibres, are not owing merely to the peculiar structure and arrangement of their parts as mechanical organs, or even to the sole efficacy of any material powers; but to their being endued with feeling, and animated by a sentient principle. Whence it follows, that the motions of the heart and other muscles, after death, or their separation from the body, must proceed from their sensibility. As long as this sentient power remains, or is but little impaired, they are impatient of any irritation, and are, therefore, alternately contracted and relaxed; but when it becomes considerably weaker,

stronger

stronger *stimuli* are required to rouse them into action, and even then their motion is more languid.

DR *Harvey*, whose mind was neither blinded by prejudice, nor prepossessed with any favourite theory, but who formed his judgment of things, not as imagination might suggest, but from repeated experiments and observation, ascribes, without the least doubt, the various and irregular motions of the chick's heart, when irritated by different *stimuli*, to its being endued with sense *; and therefore compares it to an animal which lives, moves, and feels.

THE motions of the heart from *stimuli* greatly resemble the alternate contractions of the *panniculus carnosus* of brutes, when their skin is tickled or stung by insects: and as this muscle cannot properly be considered as a mere mechanical organ, but as something animated, which endeavours to throw off whatever affects the surface of the body with any disagreeable sensation; so the motions of the separated hearts of animals, are not to be ascribed to any property

* De generat. animal. exercitat. 17.

perty they can be possessed of as mere material organs, but to their being still endued with some kind of life and sense, which makes them shew an impatience of whatever hurts them, and endeavour, by their alternate contractions, to throw it off.

24. AT eleven o'clock in the forenoon, I injected a solution of *opium* in water into the stomach and guts of a frog, both by the mouth and *anus*. In less than a quarter of an hour, it had lost a good deal of its vivacity and power of motion, and, when touched or pricked, it dragged its limbs as though their muscles had been in some degree paralytic. In little more than half an hour, it seemed to have lost all power of motion. At two in the afternoon, when I opened it, I found the auricle of the heart, with the large vessels attached to it, greatly distended with blood; but there was not the least motion either in the heart or its auricle: nay, so very insensible were these parts become of any *stimulus* or irritation, that neither tepid water, nor pricking or tearing their fibres, had any influence in exciting

citing them into motion. Hot water, indeed, being poured into the *thorax* and *abdomen*, made the heart and intestines suddenly shrink and contract, in the same manner as the flesh of any dead animal does when immersed in boiling water; but produced no alternate contractions like those which follow the action of *stimuli* upon the muscles of living animals, or of such as are newly dead. Afterwards, I cut off this frog's head, and with the point of a probe pressed and broke down the spinal marrow into a pulp; but did not observe the least motion or convulsion in any part of the body.

25. AT half an hour past one in the afternoon, I injected a solution of *opium*, as above, into another frog, and opened it an hour after. The auricle and great vessels leading to the heart were more than usually filled with blood, but not so much as in the last experiment. The heart still continued its motions, but much more slowly than in a sound state: its pulsations followed each other after an interval of about $3\frac{1}{2}$ seconds: the distended auricle always contracted

tracted first, and, after it, the ventricle. No convulsions happened in any part of the body from irritating the spinal marrow, nor were any of the muscles of the limbs or trunk brought into contraction by pricking or tearing their fibres.

26. I forced down into the stomach of another frog a smaller quantity of a solution of *opium*; and, upon opening its *thorax* an hour and three quarters after, I found its heart beating regularly, but as slowly as in the last experiment: when I cut it out of the body, and laid it on a plate, it renewed its pulsations faster, *viz.* once in two seconds; but, after five or six minutes, they became as slow as at first.

α SINCE, from these experiments, it appears, that *opium*, internally applied, soon renders the motion of the heart in frogs three or four times slower than it naturally is, and, at length, puts an end to it entirely, so that the causes which use to renew it, prove quite ineffectual for that purpose; and since *opium* received into the stomachs of animals, is well known to destroy the
sense

sense of feeling, either in the whole, or in part, as its dose is greater or less; is it not highly probable, that *opium* stops or retards the motions of the heart, only as it renders it wholly, or in a great degree, insensible of the *stimulus* of the returning venous blood; and that the contractions of the heart, both in the body and after it is separated from it, are owing to the sentient power of its nerves and fibres, by which it is made capable of being properly affected by various *stimuli*?

β As the heart continued to beat after the muscles of the trunk and limbs were no longer affected by any irritation; it follows, either that its nerves and fibres are endued with a higher degree of sensibility than those of the other muscles, or, at least, that their sensibility is not so soon destroyed by the *laudanum*.

γ DR KAAU has observed, that the convulsive motions which were excited by irritating or breaking down the brain of a dog to whom he had given six grains of *opium*, were an hundred times less remarkable than those he had been in use to observe in other
dogs

dogs who had got nothing to lull their senses * ; and experiment 25. above, shews, that no convulsive contractions are produced, either by irritating the muscles themselves, or the spinal marrow of a frog, an hour after a solution of *opium* is injected into its stomach and intestines: from which this inference is obvious, *viz.* that convulsions excited in dying animals, or such as are newly dead, by dissecting the spinal marrow, pressing it with a probe, or breaking down the brain, are solely owing to the sensibility of these parts to any irritation, and not to the spirits being mechanically propelled through the nerves into the muscles, either by the cut vessels of the *medulla* or brain retracting themselves † ; or by the pressing power of the probe or dissecting instrument applied to them.

IT has, for many years, been the prevailing opinion, that *opium* produces its *first* and most remarkable effects on the body, not by mixing with the blood, but merely

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* Impet. faciens. N° 435.

† *Kaau* impet. faciens, N° 333.

by its immediate action on the nervous *pillæ* of the stomach, whence the brain and whole nervous system are affected in a very surprising manner. In support of this opinion, many arguments have been advanced, some of greater, others of lesser weight: but the following experiments compared together, put the truth of it beyond doubt.

27. A frog continued moving its limbs, turning from its back to its belly, and leaping about for above an hour after I had cut out its heart; and was not quite dead after two hours and a half.

28. FIVE minutes after taking out the heart of another frog, I injected a solution of *opium* into its stomach and guts. In less than half an hour it seemed to be quite dead, and neither pricking, tearing, nor cutting its muscles caused any contraction in them, or any motion in the parts to which they belonged. A probe pushed into the spinal marrow, after cutting off its head, made its fore legs contract feebly.

SINCE

SINCE, in this frog which was deprived of its heart, the parts of the *opium* could not possibly be mixed with the mass of blood, or be conveyed along with it to the brain, their effects must necessarily be deduced from their direct action upon the nerves and fibres of the organ to which they were immediately applied *. But to return from this digression.

SINCE the sensibility of our fibres is owing to their being animated by a living principle different from matter, and of powers superior to it (Sect. x.), it may be objected, that if we ascribe the motions of the muscles after death, or their separation from the body, to their being endued with sense, we must not only suppose the soul to continue present with the body after death, but also to be extended and divisible.

BUT, though these objections, as they are founded in our ignorance of the nature of the soul, and its union with the body, and of the manner of their mutual action upon each other, ought to have little or no regard

* For a further account of the action of *opium* see *Edinburgh Physical Essays*, vol. ii. art. 20, and *Physiolog. Essays*, Edit. 2. p.

gard paid them in a Physical inquiry ; yet, to clear our subject, as much as possible, of all difficulties, we shall consider them particularly.

α I think it is not only probable, but even demonstrable, that the soul does not immediately leave the body upon a total stoppage of the heart's motion, and, consequently, of the circulation of the blood, *i. e.* upon what we usually call DEATH *, but continues for some time at least present with it, and ready to actuate it. Thus, a variety of insects, bats, hedge-hogs, and several other animals, which continue in a death-like state in the cold winter-season, are restored to life by the kindly warmth of the returning spring, which, as it stimulates the solids into contraction, as well as rarifies and agitates the fluids, gives the latent soul an opportunity of shewing itself by its effects : yet, in these animals, during the cold weather, there is no circulation of the blood ; they are quite destitute of feeling, may be torn and cut in pieces, without shewing

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* By death is here meant the general death of the body as a system, and not the particular death of the several parts, which does not happen for some time after.

ing that they have any sense of pain, and cannot be distinguished from such animals as are really dead, except in this single circumstance, that, by the assistance of warmth, they may at any time be brought to life.

IN the Northern countries, magpies and other smaller birds, after being frozen by the excessive cold, have been soon brought to life again by warmth *; nay, several of the human kind have been recovered by agitating their bodies, blowing into their lungs, or exposing them to heat, after having been for hours, nay, sometimes days, to all appearance, dead, without pulse, breathing, or any degree of natural heat. Had not the soul been present with such bodies, and ready to actuate them, is it to be imagined, that blowing air into the *anus* or lungs, that heat, friction, or any other *stimuli*, could, as it were, by some magic charm, have called it back from distant regions? Upon the whole, it seems certain, that, after death, or an entire stop of all motion in the bodies of animals, the soul still remains present with them, and can be again

* Flora Siberica, prae fat. p. 73.

gain brought to exert its influence, by various kinds of *stimuli* applied to their different parts. May not then the same principle continue present with the several muscles after they are separated from the body, and be the cause of their motions when irritated? And is it not reasonable to think, that the renewal of life in a frozen magpye, and of motion in the frozen heart of a salmon *, by exposing them to the heat of a fire, was owing to the same cause, *viz.* to the living or sentient principle, which being present with the body of the magpye, and the separated heart of the salmon, was excited by the *stimulus* of heat to put them in motion? But here it will be said, that, not only contrary to the opinion of many Philosophers, we suppose the soul to be extended, but also, in opposition to them all, *seem* to make it divisible; which is the second objection mentioned above, and to which I now proceed to give an answer.

β As the schoolmen supposed the DEITY to exist in every *ubi*, but not in *any place*, which, as a learned and acute writer has

* *Peyer* Parerg. anatom. 7. p. 200.

has well observed, is to say, in *Latin*, that he exists *every where*, but in *English* *no where*; so they imagined the soul of man not to occupy space, but to exist in an indivisible point. Yet, whoever considers the structure and *phænomena* of the animal frame, will soon be convinced that the soul is not confined to an indivisible point, but must be present at one and the same time, if not in all the parts of the body where the nerves are found, yet, *at least*, at their origin; *i. e.* it must be, at least, diffused along a great part of the brain and spinal marrow. Nay, while, in man, the brain is the principle seat of the soul, where it most eminently displays its powers; it seems to exist or act so equally through the whole bodies of insects, and other animals of the lowest class that its power or influence scarce appears more remarkable in one part than another: and hence it is, that, in such creatures, the several parts of the body live much longer after being separated from each other, than they do in man and the other animals more nearly resembling him, where the soul seems chiefly to act on the different parts by means
of

of their connection with the brain and spinal marrow ; or, at least, where the cutting off such connexion, soon renders the parts unfit to be any more acted upon by it.

IT was not, therefore, altogether without reason, that some of the greatest Philosophers of the last and present age, supposed the soul to be extended *.

BUT if the soul, without extension, be present at one and the same time in different places of the brain ; and if, in many animals, it can act along the spinal marrow for a great while after the head is cut off, why may not it also actuate parts separated from the body, without being extended ? On the other hand, if we allow the soul to occupy space, I do not see why it may not
continue

* *Cassendi, Dr Henry-More, Sir Isaac Newton, Dr Sam. Clarke.*

Cassendi argued for the soul's being extended in the following manner. If it be said, that the soul resides in a point of the brain, this is either physical or mathematical ; if physical, the difficulty still remains, because this is extended, and consists of parts, and consequently the soul must be extended which occupies it : if mathematical, which has no dimensions, how can the nerves, which are not mathematical lines, all terminate in that which hath neither length, breadth, nor thickness. *Cassend. object. contra meditat. Descartes, p. 32. 33.*

continue to be present with the parts of its body after they are separated, as well as when they were united. And with respect to the divisibility of the soul, which is generally thought to follow from the supposition of its being extended; why may it not be a substance so perfectly and essentially one, as that a division or separation of its parts would necessarily infer a destruction of its essence? Further, if the soul can be present in all or in any considerable part of the body at one and the same time without being discernible, its sphere of existence being so much increased, as to act upon the parts when separated, will not infer its divisibility. As the DEITY is every where present, and, in the infinitely distant parts of space, actuates at the same time a vast variety of different systems, without any inconsistency with his UNITY or INDIVISIBILITY; so, may not the souls of animals be present every where in their bodies, actuating and enlivening, at the same time, all their different members? Nay, further, when the fibres and threads connecting some of these parts are

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divided,

divided, may not the soul still act in the separated parts, and yet be only ONE mind?

IT must be owned, there is a great deal of difficulty and obscurity in these matters. But what *hypothesis* can we embrace that will clear us of them, or to what part of nature can we turn our inquiries where we shall not find something to puzzle us, some mystery at last which we cannot unfold? Nor is this to be wondered at; since, in the present state, our knowledge is very much limited, and we have only access, as it were, to the surface of things! But because we cannot explain fully, are we therefore in no ways to attempt explaining the operations of nature? Because, in accounting for the spontaneous motions of animals, and shewing their dependence on the soul, there occur some difficulties with respect to the nature of an immaterial substance, its manner of existing, and way of acting upon, or being present with the body; are we therefore to deny the reality, influence and action of this principle, which, from a variety of arguments, appear undeniable? At this rate, we ought to give up all inquiry into the
works

works of nature, and, with our arms across, sit down contented in ignorance !

BUT, not to perplex ourselves any longer with metaphysical difficulties, we shall recite a few experiments and observations, from which we are led, by the most obvious analogy, to conclude, that the motions of the separated parts of animals are owing to the soul or sentient principle still continuing to act in them.

29. A frog lives, and moves its members, for half an hour after its head is cut off * ; nay, when the body of a frog is divided in two, both the anterior and posterior extremities preserve life and a power of motion for a considerable time.

30 A young cock, whose head Dr *Kaau* suddenly cut off with a sharp razor, as he was running with great eagerness to his food, went on in a straight line 23 Rhinland feet, and would have gone farther had he not met with an obstacle which stopt him †.

The

* *Kaau* impet. faciens, N° 331.

† Ibid.

The story, therefore, mentioned by Lord *Verulam*, of an ostrich running along the stage after its head was struck off with a forked arrow by one of the *Roman* Emperors, is no ways improbable *.

31. A viper, after being deprived of its head and intrails, moved towards a heap of stones in a garden where it used to hide itself †.

32. THE bodies of vipers not only move two or three days after they have been deprived of their skin, head, heart and other bowels, but are also manifestly sensible of punctures, by means of which they may be made to move with greater vivacity. ‡

33. THE female butterflies into which silk worms have been metamorphosed, not only admit the male, after losing their heads, but also lay eggs ||.

34.

* Sylve Sylvarum, on the word *life*.

† *Kaau* impet, faciens, No 331.

‡ *Boyle's Usefulness of Experim. Philos.* part 2. p. 16.

|| *Ibid.*

34. *REDI* informs us, that a land tortoise, whose brain he extracted by a hole made in its scull, in the beginning of *November*, lived to the middle of *May* following. Immediately after the loss of its brain, it shut its eyes, nor ever opened them any more, but continued to move and walk about until the time of its death. When the scull was opened, its cavity appeared quite clean and smooth, and nothing was found in it except a small dry clot of blood. The same experiment he repeated on various other tortoises, some of which lived a longer, others a shorter time, but none of them less than fifty days *.

35. A large tortoise, whose head *Redi* cut off, allowing the blood to flow freely from the open vessels of its neck, lived after this twenty-three days; and though it did not walk about like those which were deprived of their brain, yet as often as its fore or hind feet were pricked, it moved them with great force, and was otherwise convulsed. In two tortoises which he opened

* Observation. circa animal. vivent. p. 209. & 210.

ed fifteen days after decollation, he saw the heart beating as in a living animal, and the blood circulating through it *.

HERE, we are naturally led to observe, that while those animals who have a small brain and large spinal marrow, live long after decollation; man, and most quadrupeds, which have the brain remarkably large, survive the loss of it only for a few moments.

α IF the motions of a tortoise, after decollation (35.), or the loss of its brain (34.), cannot proceed from mere mechanism, but must be undoubtedly ascribed to the living principle which was the cause of its motions in a sound state; and if the same is true of the actions performed by butterflies after the loss of their heads (33.); it must follow, that the motions and other signs of life which are observed in the body and limbs of a frog for above half an hour after its head is cut off (29.), are to be attributed to the sentient principle, to which its motions and actions were owing, when in an entire state; and if so, then the motions of
this

* Observat. circa animal. vivent. p. 212. 213.

this body, when divided into two parts, must also be referred to the same cause, since they are of a like kind, although of shorter duration. Shall we then deny that the motions of its separated heart and limbs, which are similar to these, and are increased and renewed by the application of the same causes, proceed from the sentient principle still acting in these parts? This would be to neglect the strongest analogy; and must be the more inexcusable, as no other cause can be assigned, which accounts so well for the appearances. *

WE

* The learned Dr *Porterfield*, who supposes, with *Stahl* and others, that the motion of the heart is continued and regulated by the soul acting, as a wise and rational agent, with a view to the good of the body, ascribes the alternate contractions of the heart, after its connexion, by means of the nerves, with the brain is cut off, to some power depending on its mechanical construction †. But if the motions of a viper's heart for three days after its head has been cut off, and those of the heart of a tortoise for six months after the loss of its brain, may be owing to a mechanical power resulting from their particular structure, why may not the motions of the heart in these as well as all other animals, from the beginning to the end of life, be owing to mechanism *alone*?

Indeed, there cannot be a stronger argument of the weakness of the *Stahlian* account of the heart's motion, than that one of

its

† See Dr *Porterfield's* treatise on the eye, vol. ii. p. 166. and 167.

β WE have no other way to satisfy ourselves that an animal is alive, or endued with feeling, but by observing, whether it shews an uneasiness when any thing hurts, or tends to destroy any of its parts, and an endeavour to remove or avoid it. Since therefore the bodies of vipers make just the same kind of motions when pricked with a sharp instrument, two or three days after losing their head, heart, and other *viscera*, as if they were entire (32.); we are naturally led to conclude, that they are still, in *some sense*, alive and endued with feeling, *i. e.* animated by a sentient principle. And as the muscular parts of these creatures move after being cut in pieces, and are sensible of punctures, it also follows, that they continue still to be animated*.

γ *Lastly,*

its ablest defenders has been reduced to account, in such a manner, for the motions of that organ after its connexion with the brain is cut off, as *in fact* to give up at once, all that he had advanced to prove the necessity of calling in the power of the mind to explain the vital motions.

* It has been objected, that the separated members of animals, though they continue to move for sometime, are nevertheless

γ *Lastly*, If the motions of the muscles in a cock's limbs after decollation (30.),

I i i are,

theless neither animated nor endowed with *any kind* of sensibility, otherwise the animal to which those members belonged, ought to feel pain when they are irritated.

As I have given an answer to this objection elsewhere *, I shall only observe here, that since the nerves, which are continuations of the medullary substance of the brain and spinal marrow, have been proved to retain their powers of feeling, and of putting the muscles in motion, for some time after their connexion with the brain is cut off †, we have reason to believe that the motions excited by *stimuli* in the muscles of animals, after they are separated from their bodies, are owing to *some kind* of feeling or *simple* sensation (such as oysters and other animals of the lowest class, who have no brain, are endued with) in those muscles or their nerves, which though not attended with any *reflex consciousness*, a power the soul only exercises in the brain, is nevertheless the immediate occasion of all those motions which arise from the irritation of the fibres of the muscles, whether they be connected with the other parts of the body, or newly separated from them.

And here it is worth remarking, that, while those motions which are occasioned by stimulating the fibres of any muscle, continue for some little time after its communication with the brain, by means of the nerves, has been cut off; such motions as proceed from sympathy, and are owing to the irritation of some distant part, cease as soon as the brain is rendered unfit for action, or the communication with it is interrupted, because they depend on a perception in *that organ* from which the nerves proceed, and where *alone* the cause of their sympathy is to be found.

* See my *Physiological Essays*, edit. ii. Appendix, p. 259 and 260.

† Ibid. p. 245, &c.

are, without dispute, owing to its soul; may we not also ascribe to the same principle, the like, but less remarkable, motions, in men and quadrupedes, after their heads are struck off; and, consequently, the tremulous motions and palpitations of their hearts too, after death or separation from their bodies.

To sum up all in a few words; from what has been said, it appears undeniable, that the involuntary motions of living animals, and the alternate contractions of their muscles, after the general death of the body, or their being separated from it, are owing to one and the same cause; *viz.* an irritation of their fibres or nerves, or of such parts as are nearly connected with them. If then, as we have shewn (Sect. x.), that the motions of animal fibres, from a *stimulus*, most certainly bespeak a feeling, and cannot be explained unless we admit it; and if feeling be not a property of matter, but owing to a superior principle, it must follow by necessary consequence, that the motions of the heart, and other muscles of animals, after being separated from their bodies, are

to

to be ascribed to this principle ; and that any difficulties, which may appear in this matter, are owing to our ignorance of the nature of the soul, of the manner of its existence, and of its wonderful union with, and action upon the body.

CONCLUSION.

AS Philosophical inquiries, however agreeable and entertaining they may be to the mind, become still more interesting when they can be applied to practice ; I intended to have shewn, how far the theory of the vital and other involuntary motions, which we have endeavoured to establish, may be useful towards explaining the nature of several diseases, and consequently towards pointing out the most proper method of curing them. But, as this *Essay* has swelled to a much greater bulk than I at first expected, I shall now, omitting that part of my design, conclude with a reflection of a different nature.

FROM

FROM what has been offered, then, in the preceding pages, it may appear, how unjustly the study of Physick has been accused of leading men into Scepticism and irreligion. A little Philosophy may dispose some men to Atheism ; but a more extensive knowledge of nature, will surely have the contrary effect. If the human frame is considered as a mere CORPOREAL system, which derives all its power and energy from matter and motion ; it may, perhaps, be concluded, that the IMMENSE UNIVERSE itself is destitute of any higher principle : but if, as we have endeavoured to shew, the motions and actions of our small and inconsiderable bodies, are all to be referred to the active power of an IMMATERIAL principle ; how much more necessary must it be, to acknowledge, as the Author, Sustainer, and Sovereign Ruler of the universal system, an INCORPOREAL NATURE every where and always present, of infinite power, wisdom, and goodness ; who conducts the motions of the whole, by the most consummate and unerring reason, without
being

being prompted to it by any other impulse, than the original and eternal benevolence of his nature !

*Nam quis non videt, finitæ si breve corpus
Subjicitur menti, mens quanta sit illa supremo
Quæ regit arbitrio vastum quem condidit orbem ?
Non poterit sine consilio tam parva moveri
Machina, tam fragilis ; te judice, tanta regetur
Mentis inops ! Credant Epicuri de grege porci*.*

THE true Physiology, therefore, of the human body, not only serves to confute those Philosophers, who rejecting the existence of IMMATERIAL BEINGS, ascribe all the *phenomena* and operations in nature to the powers of matter and motion ; but, at last, like all other sound Philosophy, leads us up to the FIRST CAUSE and supreme AUTHOR of ALL, who is ever to be adored with the most profound reverence by the reasonable part of his creation.

* Polignac. Anti-Lucret. lib. 5. lin. 1376, &c.

being prompted to it by any other impulse
than the original and eternal benevolence
of his nature.

Now this new state of the human system
is a new state of the human system, and
the right and wrong of conduct are
not the same as before. The right and
wrong of conduct are not the same as
before. The right and wrong of conduct
are not the same as before.

The true Philosophy, therefore, of the
human body, not only serves to connect
those Philosophers who reject the exist-
ence of IMMATERIAL BEINGS, with all
the phenomena and operations in nature to
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reasonable part of his creation.





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